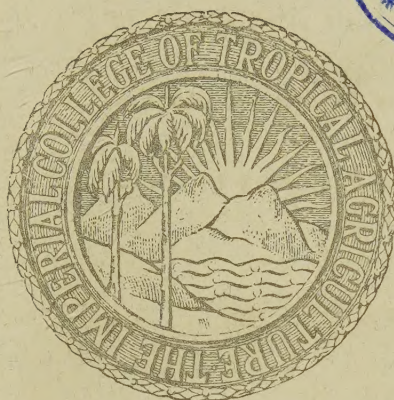
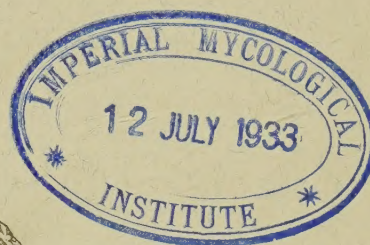


SECOND ANNUAL REPORT ON CACAO RESEARCH 1932



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SECOND ANNUAL REPORT

ON CACAO RESEARCH 1932.

PLATE I



FIG. 1
Green



FIG. 2
White



FIG. 3
Green-White

PLATE II



FIG. 4
Splashes of red on green



FIG. 5
Splashes of red on white



FIG. 6
Partial red on green



FIG. 7
Partial red on white

PLATE III



FIG. 8
Green in furrows



FIG. 9
White in furrows



FIG. 10
Very dark red



FIG. 11
Dark red



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SECOND ANNUAL REPORT ON CACAO RESEARCH 1932.

A.—BOTANICAL SECTION.

THE BOTANICAL PROGRAMME OF 1932.

By E. E. CHEESMAN, M.Sc.

WORK during 1932 has followed the lines laid down in the 1931 Report, and detailed accounts of advances are again presented by the officers responsible for them. A brief summary under the three headings previously employed will illustrate the unity of the programme.

Propagation Studies.

Following up the results of a general survey of possibilities in 1931, attention in 1932 has been concentrated mainly on improvements in the technique of rooting softwood cuttings. The conditions for successful rooting have been fairly well standardised, and although further improvements will doubtless prove possible, the methods now available will serve for the production of uniform experimental trees, and are already being turned to that practical end. These methods are described by Mr. Pyke, in amplification of his previous notes.

Attention has also been given to layering, as the most promising means of multiplying, in the nursery, strains isolated on their own roots as cuttings. The behaviour of layers is liable to change with age, and as we now have considerable experience of layering seedlings, interest in 1933 will centre mainly on plants raised originally from softwood fan cuttings and subsequently pegged down in the nursery. In particular, it is hoped to obtain information concerning the differentiation of "fan" and "chupon" buds, which affects so profoundly the habit of the vegetatively propagated tree.

It is anticipated that in 1933, routine propagation of selected trees on their own roots will demand at least as much attention as further investigations.

Genetic Survey.

It will be remembered that in 1931 the genetic survey was concerned with intensive measurements of three hundred trees, with respect to pod dimensions and number of beans per pod. Data concerning the weight of wet cacao per pod had to be withheld until a full season's records should be available, but they are now presented in completion of the 1931 programme.

In 1932, similar measurements were made on the same trees in order that the differences in two seasons (quite dissimilar as it rather fortunately happened) might be estimated. Such differences were found to be small, and we feel

justified in concluding that the pod dimensions which characterise any given tree can be measured once and for all by a single sample of thirty pods taken about the time of maximum bearing. Bean number and wet cacao weight are more variable, but the standard sample of thirty pods gives a mean usually within 10 per cent. of the truth, and for practical purposes such precision is adequate.

With the last of the preliminaries thus satisfactorily settled, the survey was extended over a wider area, and as a result Mr. Pound is now able to present frequency curves for all the characters studied, constructed from about 1,200 trees located on eight stations in different parts of Trinidad. The smoothness of the curves in every case indicates that the composite sample taken is truly representative of Trinitario cacao, and although it is unlikely that it contains the true extremes, it can be used as a scale model of the population available for selection. The preliminary survey of quantitative variability is thus completed.

It would obviously facilitate selection very greatly if associations could be found between yield or quality on the one hand and what may be called "type" on the other; if, in other words, quantitative characters could be correlated with qualitative. With that end in mind, Mr. Pound has made a qualitative survey side by side with his quantitative observations. He had first to evolve a scheme of classification more precise than that in general use, and by a partial separation of the components of shape and colour in the pod he is now able to divide the continuous series of intergrading forms which make up Forastero cacao into 110 classes. Considered purely as an artificial system his scheme is a material advance on anything previously attempted, and at the same time it is better than a wholly artificial system in being founded on characters which should ultimately prove capable of genetic analysis.

His comparisons of qualitative with quantitative characters show that hopes of finding useful correlations have as yet been very imperfectly fulfilled, and for practical selection we shall apparently have to confine our attention to quantitative characters, but his studies lose on that account none of their intrinsic value, and they will find a further application when in due course clone descriptions have to be compiled.

A third aspect of genetic survey is presented in the note on the seedling progeny of a single tree. We were fortunate in finding such a progeny in bearing, as trees of well documented ancestry are everywhere rare, and once more our grateful thanks are due to the Trinidad Department of Agriculture for the use of material unavailable elsewhere and essential to our purpose. The quantitative characters of this particular progeny happen to be below our selection standards, but there is no reason to suppose that the main conclusion would have differed very much had the parent tree been of a better type. That conclusion is that although the progeny vary widely the variation is continuous and the standard reached by the greatest number of individuals is almost exactly the standard of the parent. Such a conclusion has a practical bearing on the question of the use of selected seedlings pending improvements in vegetative propagation.

The sum of information gathered in the two years of survey provides adequate criteria for selection, and the programme of 1933 will be mainly concerned with seeking and collecting the most promising individuals for propagation and further study. Already some 200 trees found on various estates during the survey have been tagged, as outstanding in one or more respects, and the aim is to raise the number to 1,000 during the coming crop.

The criteria of selection and an outline of the future programme are given in Mr. Pound's paper on that subject, but there is one aspect of the matter to which attention may be specially drawn. One of Mr. Pound's most important discoveries is that among trees with a high "pod value" (*i.e.* weight of wet cacao per pod) the greater proportion have also a high mean weight of bean. This means that selection can be based on yield and yet almost automatically lead to improvement of quality, since size of bean is an important component of quality from the manufacturers' point of view. Selection *in the first place* for a large and productive pod rather than for heavy bearing in number of pods per tree seems to have nearly every argument in its favour, and this principle emerges as a very practical outcome of our work to date.

Studies of Fruitfulness.

The observations in general physiology mentioned in last year's summary were continued in 1932. Mr. Pound has combined much of his work into a general discussion of the factors affecting fruit setting, in which he adduces further evidence of the importance of partial self-incompatibility, apparently of common occurrence among the tree population.

Mr. Pyke's task has been to collect full data of tree behaviour, which we judged an essential preliminary to any planned experimentation. His paper on this subject is inevitably mainly descriptive, but it will form the starting point of various lines of investigation.

We now know exactly how two sets of trees behaved, week by week over a period of eighteen months, with respect to flushing of foliage, flowering, fruit-setting, and production of crop, and can proceed to more critical study of the inter-relationships between these various expressions of vitality. It is obviously impracticable to present all the data, and a selection has been made to illustrate those features which we consider most worthy of study.

Collection of this kind of data has been concluded for the present, as it has a limited value until such time as we can commence continuous observations on clonal material and under partially controlled conditions.

Other Work.

In addition to the three main lines of our scheme we carried out during 1932 another piece of work which has already been published in the pages of *Tropical Agriculture* (Vol. IX, pp. 277-288) but calls for mention here to complete our record.

The West Indian Conference of Agricultural Officers held at the Imperial College of Tropical Agriculture in 1930 set up, under the chairmanship of the Director of Agriculture, Trinidad, a permanent committee known as the Field Experiments Committee "to consider for the guidance of Agricultural Officers of the Conference Colonies, methods of planning, executing and reporting field experimental investigations, and to devise in collaboration with these Officers methods of co-ordinating such investigations". At a later date, the chairman asked a sub-committee to deal with the specific problems of field experimentation with cacao. It appeared to this sub-committee that no problem was of more pressing urgency than that of the conditions to be observed when laying down experiments on existing plantations, and that the crux of this problem was the size of plot to be adopted, as determined by the degree of variability from tree to tree in the field. Yield figures, collected by the Trinidad Department of Agriculture over a number of years at River Estate, provided the necessary data, which could not be obtained in such complete form anywhere else in the world.

It seemed most appropriate that a Cacao Research Officer should undertake the analysis, as the problem is an important one to all cacao-growing countries. Mr. Pound therefore made the necessary statistical calculations, the writer collaborating in presentation, and the conclusions arrived at were as follows:—

1. In cacao reasonably homogeneous with respect to age, field experiments on a Latin Square lay-out with 12 to 18 trees per plot may be expected to demonstrate differences due to treatment of the order of 30 per cent.

2. Under similar conditions the use of two or three years' previous records of natural yield, applied by Sanders' method, may double the precision.

3. Under some circumstances the combination of consecutive years in pairs may reduce the standard error as much as the use of regression.

4. In cacao heterogeneous for age, field experiments cannot be recommended unless previous records of natural yield are available.

5. The use of records for three years previous to the experiment may increase precision as much as eightfold, and thus bring within the bounds of practicability, experiments on cacao heterogeneous for age. The precision, however, still remains below that obtainable with cacao uniform in age.

6. The value of previous records varies with circumstances, and cannot be stated in general terms, because the inclusion of an abnormally good or an abnormally bad year among them may result in a loss rather than a gain in precision.

As a corollary to the same investigation Mr. Pound published a note on "The Significance of the Relation between Total Variance and Mean Annual Yield" (*ibid.*, pp.288-290) in which he showed that :

1. It is found that in fields heterogeneous for type and age there is a very significant positive correlation between the mean annual yield in pods per tree and the total tree-to-tree variance.

2. On statistical grounds this must be due to the fact that in good years the yield of good bearing trees draws far away from the yield of poor bearing trees. The proportionate increase of crop may possibly be about the same for all trees but in any case good bearing trees have a greater capacity for increase of yield than poor bearing trees.

3. This contention is supported by the number of good and poor bearing trees occurring each year.

4. There are two factors responsible for capacity to yield, the size and age of the tree, and its inherent capacity to produce fruit. Therefore, in selection on the basis of yield of pods alone, attention must be paid more to the number of pods produced per unit area of land than to the actual number of pods produced by the tree.

THE VEGETATIVE PROPAGATION OF CACAO.

II.—Softwood Cuttings.

BY E. E. PYKE, B.Sc.

During 1932, propagation work under the Cacao Research Scheme was concentrated mainly upon the rooting of softwood cuttings and upon stooling and layering processes, since these proved in 1931 to be the most promising lines of investigation for the respective purposes of isolating selected types and of multiplying them on a nursery scale. The technique of rooting softwood cuttings was considerably improved, and the preliminary account of it given in the last report now requires correction and amplification.

Type of Material Used.

Experience of the characters indicating material suitable for propagation was extended in two directions. First, further evidence was acquired of the connection between the condition of the tree and the behaviour of cuttings taken from it, and in the second place chupon material was compared with the fan branch flushes formerly used exclusively.

Effect of Shade.—As before, maximum success, both in rooting and in the subsequent establishment, was obtained when vigorous flushes were used from young trees growing under medium shade. On the other hand, very little success was obtained with cuttings taken from trees growing under light shade or no shade, although vigorous cuttings were used. Several batches were tried, but always after a few days in the propagator the leaves became yellow in patches and were quickly shed, the cuttings being usually

completely bare within a week. A few cuttings which retained one or two of the upper leaves rooted, but they were not sufficiently strong to make fresh shoot growth (Table 1). The shedding of the leaves was not caused by the rotting of the cut ends, as in nearly all cases these callused over rapidly.

Table 1.

ROOTING OF CUTTINGS FROM UNSHADED TREES.

Tree.	No. Set.	No. Rooted.
Ortina trees	13	1
Young Criollo	5	2
Bud-scion from R. E. No. 1386	7	0
	25	3

Flushes grown without shade have lighter coloured leaves than shaded flushes, the internodes tend to be shorter, and the stems more rapidly lose their pubescence and become smooth and hard. Their behaviour is quite consistent with previous findings, since they may be expected to have a higher carbohydrate content than shaded flushes, and it was shewn in the 1931 Report that shoots of which the carbohydrate content is artificially increased by ringing, drop their leaves to a greater extent, and develop roots less, than control cuttings from similar shoots unringed.

Effect of Age of Tree.—On old trees, even when growing under good estate conditions, it is not usual to find a large supply of the vigorous flushes which make the most successful cuttings. Thus cuttings taken from various old trees at River Estate, notably from tree No. 1480, were much less vigorous and the rooting percentage was low. Also the few cuttings which did root made very feeble subsequent growth. Such trees usually put out a few moderately vigorous "general flushes" in the course of a year, and should fan cuttings be required, the best method would probably be by suitable heavy pruning, together with manuring, to make the general flushing as vigorous as possible.

Younger trees, up to about thirty years old, under good cultivation and fairly heavy shade, yield an abundance of good cutting material.

Characters of Good Fan Branch Cuttings.—The shoots selected were those making an extension of from nine to fifteen inches at each flush. Only completely mature flushes were taken, and when in some cases short new flushes had started, they were pruned off in making cuttings. The trees from which the bulk of the material was taken, were planted from seed about the middle of 1929, hence they were nearly three years old at the start of the experiments. They grow under a saman tree (*Samanea (Pithecolobium) Saman*), which provides medium shade, and they are protected from the prevailing winds by substantial wind-breaks. The effect of the shade, probably in conjunction with mulching, is to secure a type of growth in which the flushes are vigorous but are not "sappy", and have characteristic deep-green leaves. The average length of internode is about one inch. The diameter of a typical cutting flush is about 0.7 cms. and the pith diameter/stem diameter ratio about 1:3.5, measured at the base of the cutting, that is, near the base of the flush. Mature terminal flushes possibly root most rapidly, but rather older wood, provided it retains healthy leaves, roots without difficulty.

Comparison of Chupons with Fans.—Most of the softwood trials have necessarily been made with "fan" material, as it is available in much greater quantity than "chupon" material. However, successful rooting was obtained with small batches of suitable chupons, and the rooted cuttings were easily hardened off and made good new top growth. The terminal parts of chupons owing to their tendency towards continuous flushing, are often too soft to make good cuttings, but at certain times the chupons from layered or stooled stems behave in their growth habit rather like fans, in that they exhibit fairly well-defined "flushes" with intervening dormant stages. Chupons collected from such dormant stems rooted readily.

The layered and stooled trees which supplied the chupon soft-wood cuttings were originally from the same batch of seedlings from which

fan cuttings were taken. Hence the two classes may be considered comparable in respect of age and variety. Morphologically the chupon cuttings are distinguished from the fans by their spiral phyllotaxis, longer petioles, and lower pith/stem ratio. The leaves are of about the same colour and texture.

The time required for rooting is variable in both fans and chupons, but it appears to be somewhat longer on the average with chupons, possibly owing to their greater tendency to produce large callus. However, one chupon cutting rooted within twelve days of setting, although similar chupons taken from the same plant at the same time took about forty days to root. The average rooting time for these chupons seems to be about one month.

The rooting habits of the fan and chupon cuttings are different. In both types the roots push through the stem tissues horizontally, but whereas in fan cuttings they continue to grow almost horizontally for several centimetres, in chupon cuttings they usually grow vertically as soon as they emerge from the stem. The subsequent top growths are similarly contrasted. With fans, the terminal bud, when present, usually flushes, together with several lateral buds, sometimes low on the stem, and the flushes tend to straggle out of the vertical. With chupons, however, either the terminal bud, or if it is absent, a single lateral near the top of the cutting, grows out to a vertical erect chupon shoot. Fig. 1* illustrates typical fan and chupon cuttings.

Possibilities of Chupon Material.—Cacao trees in plantations frequently send up chupon suckers from the base of the trunk, and occasionally from aerial branches. These chupons vary greatly in vigour and degree of hardness. The very vigorous and sappy shoots were found under trial to be highly susceptible to attack by "chupon wilt" (*Phytophthora palmivora*) in the propagator, and this fungus, causing the stems above the sand to rot, will probably limit the use of soft chupons as cuttings. However, batches of harder chupons were less liable to the disease, and shewed an average rooting percentage of 68. These chupons were taken when they were temporarily dormant. They had lighter coloured leaves than the chupons from the layers, and had a mean pith/stem ratio of 1:2, as against 1:3 for the layer chupons.

In general, chupon cuttings give a moderately high percentage rooting and of successful establishment. Thus they should be of considerable use in vegetative propagation. The rooting and shooting habit is such as to give promise of a shapely tree, closely approaching the seedling type. They appear to be somewhat less exacting of very closely controlled conditions

* All text figures will be found at end of this section.

during rooting and hardening off than fan cuttings. Table 2 gives the rooting percentages of all the batches of chupon cuttings set in the cool frame.

Table 2.
ROOTING OF CHUPON CUTTINGS.

Batch.	Tree.	No. in Batch.	No. Rooted.
1	Stooled seedling	4	4
2	River Estate, shoots from a mature tree stump ..	5	3
3	Stooled seedlings	12	11
4	Miscellaneous seedlings, tops cut off and set as cuttings	6	6
5	Basal chupons from mature trees, Caura	16	4
6	Basal chupons from mature trees, St. Augustine ..	20	15
7	Stooled seedlings	5	4
	Total	68	47

Manipulation of Material.

No advantage in rooting was gained in cacao cuttings by making the cuts at the nodes, hence for convenience in setting the cut was made just above a node and when necessary the lowest leaf was trimmed off to give about $1\frac{1}{2}$ inches of clear stem at the base. In collecting, the cuttings were made about an inch longer than the desired length, and this inch was trimmed off with an oblique cut when the cuttings were set, so as to ensure the exposure of a freshly cut clean surface. A rather steeply oblique cut appeared to give the best results. Cuttings between nine and fifteen inches long were chiefly used, and gave quick and uniform rooting under good conditions. In most of the experiments with cacao cuttings the larger leaves were trimmed back to about half their original area, and the smaller leaves to about two-thirds. This trimming is a useful practical measure, as without it the leaves tend to straggle down over one another and the lower leaves become washed over with sand. No direct comparative experiment has yet been made to determine whether the reduction of leaf area by trimming retards rooting or shooting, but it is probable that the reduction of the assimilating surface is compensated by the better presentation which the trimmed leaves offer to the light.

In setting the cuttings no attempt was made to consolidate the sand round the stems by "firming-in" or heavy watering, instead the sand was kept as porous as possible. The cuttings were set so that the ends were not more than $1\frac{1}{2}$ to 2 inches under the surface. Thus, except in a few experiments using a definitely water-logged medium, the method of setting aimed at providing very good aeration of the bases of the stems.

Media.

The coarse-grained calcareous sand used in 1931 has continued to give good results. It has the valuable properties of being well drained and of providing a very poor nidus for bacterial and fungal growth. Hence, if reasonable care be taken, cuttings keep fresh for a long time in this medium. Cacao cuttings root very well in it, and the absence of packing facilitates the inspection and transplanting of rooted cuttings with a minimum of injury to the roots. Cacao cuttings have also been rooted in a finer, non-calcareous sand, and in fine coconut fibre, but sufficient direct comparative trials between the three media, using large cuttings, have not yet been made. Both the non-calcareous sand and the coconut fibre have the practical disadvantage of requiring more careful control of watering than the calcareous sand, as they tend to pack and become water-logged. Comparative trials of several different media have been made, using single-leaf cuttings, and it is intended to use also larger cuttings in further experiments.

Propagators.

The first success in rooting cacao was obtained with the solar propagator, in which extra "bottom heat" is supplied from the sun's rays acting upon a specially designed sun-trap. Later a plain frame was used, in which no special heating was provided. The excellent results obtained with this cool frame, not only with cacao cuttings, but also with softwood cuttings of various other plants, led to work being concentrated on plain chambers of similar type.

The cool frame is made of concrete; the overall dimensions, excluding the canopy, are:—11 feet long x 6 feet wide x 2 feet 4 inches high. It is divided by one longitudinal and two transverse concrete partitions into six chambers, each having a hinged glass-lighted lid. The mean internal dimensions are:—3 feet 4 inches long x 2 feet 8 inches wide x 2 feet deep, or more accurately 62 x 81 x 103 centimetres. This gives each chamber a volume of approximately 517 litres. In one bin measured, the total depth of sand and drainage gravel was 17 cms., giving a volume of 141 litres, hence the volume of the air in the chamber was 376 litres. With 25 cuttings in the chamber (an average number readily accommodated), the volume of air per cutting is fifteen litres. It is probable that the volume of air per cutting is an important factor in softwood propagation, as it determines the amount of ventilation necessary to maintain a sufficiency of carbon dioxide for assimilation, and ventilation is limited normally by the humidity requirements.

The cool-frame chambers are protected from direct sunlight by an overhead canopy, supported on a frame of "expanded metal". In addition, removable side sheets of canvas are hung up to prevent oblique sunlight from striking on the frames. This shading, although rather heavy, ensures a moderate and even temperature in the frames, and it simplifies the control of humidity.

In addition to this cool frame, there were available two large concrete chambers in a greenhouse, which were used for hardening off rooted cuttings, but were given trials as rooting chambers. The internal dimensions of each chamber are:—9 feet 6 inches long x 3 feet 9 inches wide x 3 feet deep, giving a capacity of 107 cubic feet or 3040 litres. One chamber was covered by three glass-lighted lids, and the other was covered by a sheet of fabric ("experimental cloth"), which was kept constantly moist during propagation trials by frequent spraying. At first it was difficult to keep the air cool inside the glass-covered chamber, but this was overcome by painting the part of the greenhouse roof over the chamber with a thin coat of limewash, thus preventing direct sunlight from striking on the chamber. A high humidity is maintained

without difficulty, as the porous concrete walls can be kept moist by periodical spraying, and they act very efficiently as humidifiers. With the cloth-covered chamber, it was found that so long as the cloth was kept moist, the humidity within the chamber remained high (over 95 per cent.), but that it fell rapidly if the cloth was allowed to dry. Hence, for rooting cuttings in this chamber, constant sprinkling was necessary during the daytime. The difficulty of maintaining this is a drawback to the use of plain cloth coverings, and trials are to be made with cloth rendered semi-waterproof with linseed oil. The day temperatures in these two chambers are very constant, being about 25°C. (77°F.). The corresponding temperatures in the cool frame are about 1°C. higher (Table 3).

Table 3.

COMPARISON OF TEMPERATURES IN COOL FRAME AND GREENHOUSE CHAMBERS.

DATE.	TIME.	COOL FRAME.			GREENHOUSE CHAMBERS.	
		Pos. A.	Pos. B.	Mean.	Glass.	Cloth.
21st December, 1932	.. 2.00 p.m. ..	25.9	26.1	26.0	25	25.2
21st December, 1932	.. 3.45 p.m. ..	26.0	26.1	26.05	25	25.4
22nd December, 1932	.. 9.15 a.m. ..	24.8	25.1	24.95	24	24.0
33rd December, 1932	.. 9.00 a.m. ..	25.2	25.8	26.0	23	24.1
3rd January, 1933	.. 2.30 p.m. ..	26.8	26.6	26.7	24.8	25.4
4th January, 1933	.. 9.00 a.m. ..	26.0	26.0	26.0	24.0	24.2
5th January, 1933	.. 2.00 p.m. ..	25.9	26.1	26.0	24.8	25.0

In addition to the propagators described above, some trials have been made using pits dug in the ground, on the shaded cacao plot. The first pits were 4 feet long x 1 foot 6 inches wide x 1 foot 6 inches deep, and contained the rooting medium to a depth of about four inches. Each pit was covered with three panes of glass, each 1 foot 4 inches x 1 foot 8 inches. The trials were made during a spell of wet weather, and difficulty was experienced with flooding. Both calcareous and non-calcareous sands were tried, and also fine coconut fibre. Rooting was poor in all three media, probably partly due to the effect of the flooding. The fibre showed the quickest rooting, and the non-calcareous sand the slowest and the poorest percentage rooting.

Although the fibre showed the quickest rooting, the roots formed had a weak, thin appearance, quite different from the strong, stout roots produced in sand. Further trials are to be made when the weather is drier.

The temperatures of the media in the pits were very uniform, often varying less than 1°C. during the day, and were in general 1°-2°C. lower than those of the sand in the cool frame.

With four inches depth of medium, the air volume in each pit is 7 cubic feet, or nearly 200 litres, hence with 15 cuttings the air volume per cutting is 13.3 litres. This may be too small

an allowance to conserve sufficient carbon dioxide for assimilation in the necessarily poorly ventilated pits. Hence larger pits were made, 6 feet long x 2 feet 7 inches wide x 1 foot 10 inches deep, having an air volume of about 570 litres. These pits were each covered with a glass-lighted wooden frame. The first trials in the pits were spoilt by scorching of the cuttings, due to insufficient shade, but further trials are being made using a controllable shade of palm leaves on a bamboo framework.

Temperature Conditions in the Propagators.—With the exception of the solar propagator, all the chambers used show a very uniform range of temperature variation. A typical daily temperature variation of the sand in the cool frame is shown in Fig. 2.

The temperatures were recorded from the middle chamber of the west side. Readings A. were from a thermometer placed 2 inches under the sand at the back of the frame, about 1 inch from the concrete wall, and readings B. were from a thermometer similarly placed but in the middle of the chamber. It will be noticed from the graph and from Table 3 that there was a small but consistent temperature difference between the two positions, amounting to about 1°C. during the night and early forenoon, and

becoming practically negligible during the afternoon. The influence of the back wall is to cool the sand slightly in comparison with that in the bulk of the frame, and a corresponding marked heating influence of the front wall, due to the afternoon sun striking upon it, is shown by the curve C. The temperature of the air above the sand is considerably affected by the heated front wall in the afternoon, and rises several degrees above sand temperatures. When the sun is not directly striking on the frame, however, as in the morning or after sundown, the air temperature is practically that of the sand.

This temperature difference was correlated with a marked difference in the time required for rooting of cuttings placed in the two positions. The maximum temperature differences were obtained, as would be expected, when the opposite chambers were empty and open to the air; when they contained some sand and were closed, the temperature difference was less marked. The experiments dealing with the effect of position in the frame upon rooting, are considered under the next heading.

General Conditions for Rooting.

The excellent rooting results obtained with selected material in the cool frame suggest that the aggregate external conditions supplied by this propagator should be fairly near the optimum. The percentage rooting of the best batches is between 90 and 100. These figures are based on a comparatively small number of cuttings, as exact figures are not available for all the batches, owing to many of the slower cuttings being removed from the frames before they were rooted, to make room for fresh experiments. However, these cuttings usually rooted after being potted up if they were kept in a saturated atmosphere. Considerable variation is shown in the time taken for the appearance of the first roots in uniform batches of cuttings, ranging from fourteen days to over six weeks. Usually about 50 per cent. of the cuttings in a batch will show roots after three weeks.

The two external factors which have received most study are temperature and humidity, of which the former has already been discussed.

With cacao softwood cuttings it is necessary to maintain a practically saturated atmosphere in the chamber, not only during the induction period, but for at least two weeks after the cuttings have rooted. Even short periods of appreciable saturation deficit cause yellowing of the leaves, followed by abscission, while longer periods cause rapid drying out and death of the cuttings.

Water Content of the Medium.—Using calcareous sand in large chambers, fairly heavy watering can be used without waterlogging the sand. Under these conditions the cuttings callus and root rapidly. When the cuttings are set in sand contained in small clay pots, the drainage is much less effective and the sand becomes practically waterlogged. This inhibits the formation of

callus at the cut ends, which tend to rot. However, with vigorous material, meristematic activity occurs within the stem about $\frac{1}{2}$ cm. from the cut end, and roots develop from the stem as far as one inch from the end. The root formation is about as rapid as that of cuttings placed in the drier sand, but the roots tend to be less robust. Such cuttings, however, when transferred to drier sand just after rooting, make very rapid and vigorous root growth. (Fig. 3).

Light.—The method of shading adopted for all the propagating chambers is that of providing an overhead cover to prevent all except diffused or much weakened sunlight from striking on the frame. With the cool frame and the solar propagator, the cover is a single layer of canvas, supported four feet above the frames, and supplemented by side sheets when the sun's rays are oblique. The greenhouse chambers are protected by a thin coat of limewash on the glass roof of the house, and in addition, further diffusion is provided by the moist cloth covering of one of the chambers. The field pits are shaded by the Saman foliage and the cacao trees on one plot, and by an artificial shade of palm leaves (or cloth) on another plot. The light intensities in the different frames were roughly evaluated by exposing strips of sensitive paper (gaslight paper) for a standard time, under a negative of graduated densities, and comparing with a standard series made by exposure to the open northern sky light, under the same negative. The values obtained are given in Table 4. It

Table 4.

COMPARATIVE LIGHT VALUES IN PROPAGATING CHAMBERS.

	11 a.m.	2 p.m.
Standard (open north sky) ..	1	1
Cool Frame { bin facing west ..	1/15	1/7½
{ bin facing east ..	1/7½	1/4
Greenhouse Chambers (cloth) ..	1/60	1/60
(glass) ..	1/15	1/15
Pits in field ..	1/15	—

will be seen that the cool frame bins have much better illumination than any of the others, with a light intensity of from 1/4 to 1/15 that of the open northern sky. The bins on the west obtained less light than those to the east, due to the distribution of the top shade, but by modifying the top shade it is hoped to obtain more even illumination. A value of 1/4 to 1/8 relative illumination would probably be about the optimum for cacao cuttings.

Cuttings have been rooted in both the glass-covered and the cloth-covered greenhouse chambers, but in the latter, having a relative illumination of 1/60, the percentage rooting of a batch was only 40 and the cuttings took about

eight weeks to produce fairly large root systems. Also, most of the leaves were shed during this time, so that this dim lighting does not appear to be satisfactory for the propagation of cacao cuttings. It is interesting to note, however, that considerable root growth, and also new shoot growth, can occur at light intensities of this order.

Ventilation.—The question of the ventilation of the chambers is bound up with the conservation of atmospheric humidity, and in practice, continuous ventilation to any extent is not possible with cacao, as the humidity is lowered beyond the tolerance of the cuttings. The question however, arises whether, under the normal working conditions of the propagators, ventilation may be poor enough to prevent access of sufficient carbon dioxide for assimilation. Intermittent ventilation through periodical opening of the chambers would appear to keep the cuttings in the cool frame supplied with carbon dioxide without seriously affecting the humidity, as the chambers are usually frequently sprayed, but in pits under field conditions it is impracticable to have them frequently opened and sprayed. The ideal from the practical standpoint is to have an almost sealed pit which requires watering only every few days.

"Wall Effect" of the Cool Frame.—Stimulation of rooting by proximity of the cuttings to a porous surface is frequently mentioned in the literature on vegetative propagation and is usually ascribed to improved aeration. Macmillan (1) describes method for rooting cuttings in clay pots, making use of this principle. In the experiments with cacao, cuttings set close to the back or side walls of the cool frame rooted more quickly and made more rapid subsequent growth than those planted away from the walls. Table 5 shews the value

Table 5.

COMPARISON OF POSITIONS IN FRAME.

Position.	Near back wall.	Centre.	Near front wall.
Number set ..	20	20	10
No. rooted after 20 days ..	12	7	5
Total No. of roots ..	54	23	9
Total length (cm.) of roots ..	71.5	57.8	10.9

of this effect. The reason for this marked acceleration in the case of cacao cuttings is not yet clear. There is the possibility that it may be a temperature effect, in favour of the slightly lower average temperature near the back wall of the frame, or it may be due to some influence

(1) Macmillan, H. F. "A Handbook of Tropical Gardening and Planting." Pages 50 and 51.

of the porous concrete wall on the aeration or drainage of the medium. Further work is in progress on these points. It seems unlikely that the comparatively small differences of temperature observed should have such a marked effect upon rooting, and it is proposed to observe whether the wall has any influence when the temperature relations are altered by artificial heating so as to make the wall slightly warmer than the surrounding sand. It will be observed that rooting along the front wall, which was heated by the afternoon sun, was comparatively poor.

Treatment Subsequent to Rooting.

The best technique for obtaining successfully established cuttings was found to lie in potting up the cuttings as soon as they were rooted. In this way the set-back caused by lifting from the propagator was avoided. The potting medium used was a mixture of equal parts vegetable compost, with the sand used for propagating. Bamboo and clay pots were used; the clay pots were very much preferable to the bamboo pots, as it was easier to control watering, and they did not become septic with saprophytes. The objection to clay pots is their expense, and later experiments will be directed towards finding cheaper substitutes.

After potting up, the cuttings were kept in a closed chamber in the greenhouse for three or four weeks, by which time they had usually started to send out new shoots. They were then hardened off gradually by reducing the humidity of the chamber by raising the lid, and later they were placed in a sheltered part of the greenhouse, before being finally planted out.

Summary.

Methods are described which were found successful at the Imperial College of Tropical Agriculture for rooting softwood cuttings of *Theobroma Cacao*. Fan branches and later chupons, of different degrees of maturity, and from trees of varying ages, were tried. With both types of material the best results followed when stems of vigorous, but also rather hard habit were used, and the environment and age of the trees from which cuttings were taken both appeared to influence success. In general, failure to root followed upon shedding of the leaves in the propagator, and *vice versa*, cuttings which retained their leaves nearly always rooted.

It follows that the conditions in the propagator must be primarily adjusted to enable the cuttings to retain their leaves in a healthy condition and this necessitates a practically saturated atmosphere and a moderate temperature. The types of propagators used are described and some temperature and illumination data for them are tabulated. Best results have been obtained with a shaded concrete cool frame having six independent chambers. In this frame the rooting success of batches of good fan and chupon material is of the order of 90 per cent. and the rate of rooting

is indicated by the first signs of roots appearing on about 25 per cent. of the cuttings after two weeks, and about 50 per cent. rooted after three weeks from time of setting. The shortest time observed for rooting was 11 days, in the case of two fan cuttings, and this probably represents about the minimum time for cacao cuttings to root. The cuttings were potted for hardening off soon after they rooted, in this way damage to the roots

was minimised. Clay pots were preferable to bamboo pots for hardening off, but trials are being made with less expensive substitutes.

The reduction of the humidity in hardening off cacao must be extremely gradual to avoid desiccation of the cuttings, at least three weeks in an almost saturated atmosphere must be allowed after potting up, before the hardening proper is commenced.

THE GENETIC CONSTITUTION OF THE CACAO CROP.

BY. J. F. POUND, B.SC.

NOTE.—This paper is complete in nine sections, as follows:—

(1) *Introduction* (2) *Statistics of Pod Dimensions* (3) *Statistics of Bean Number* (4) *Statistics of Wet Cacao Weight* (5) *A Comparison of the Seasons 1931 and 1932* (6) *Summarized Results of the Quantitative Survey* (7) *The Classification and Distribution of Type* (8) *Correlations Between Type and Quantitative Characters* (9) *General Summary*.

The first three sections appeared in the *First Annual Report on Cacao Research*, 1931, pp. 10-24 the rest follow in order.

4.—Statistics of Wet Cacao Weight.

From consideration of the variability in number of beans per pod, it is only to be expected that the total weight of beans per pod will also be a very variable quantity. It is called "wet cacao weight" in order to avoid any possible confusion with "mean bean weight", which is the average weight of the single seed. In its relation to yield wet cacao weight is the most important of the statistics examined, and in this respect its wide variability is unfortunate.

Factors contributing, apart from bean number, are:—

1. The degree of ripeness of the pod.
2. The variation in weight between individual beans.
3. The time of year at which the pod matures.

Degree of Ripeness.—No critical figures have been obtained to illustrate the variation in wet cacao weight due to varying degrees of ripeness because it is difficult in the first place to judge pods on a tree of the same stage of maturity, and in the second place, to obtain sufficient at each stage for a reliable sample. There can, however, be no doubt that the contribution of this factor is large. When measurements are being made in the field, there are usually among the pods from a single tree some which are only just mature enough for harvest and others which are slightly over-ripe, the latter being those which were almost but not quite mature enough to be picked on the previous round. The discrepancy between the weights of contents of such pods is often of the order of 50-60 gms., or an average of 1.5 gms. per bean. The less ripe pods are, of course, the heavier, and the over-ripe the lighter, and it is probable that the final products of the two sets are not much different.

It may be felt that the inclusion of barely-ripe or over-ripe pods when examining trees statistically argues bad sampling but the reasons are practical ones. With picking intervals of approximately a month, the degree of ripeness within the picking must vary, but shorter intervals are not practicable in estate routine.

Variation in Bean Weight.—The weights of individual beans in a pod differ considerably, probably in part on account of segregating genetic factors. There is no direct evidence to support the popular belief that the beans in the middle of the pod are heavier than those at the ends. In many cases the terminal bean is heavier than any of the others.

Ten ripe pods were taken from one tree, and their contents weighed bean by bean. The actual bean weight varied from 1.8 to 3.2 gms. in one pod, from 1.7 to 3.0 gms. in another, from 1.4 to 2.9 gms. in a third and so on.

The weights of the first 35 beans from each pod were treated for significant differences by Fisher's Analysis of Variance method. Table 6 shows that there were significant differences between the pods of one tree ($P = < .01$), and that beans in the same pod may differ significantly from one another.

Variability between pods is due to some extent to their relative positions on the tree. The total variation in weight among the individual beans from a whole tree is wide.

Time of Year at which Pod Matures.—In January 1932, at Caura, the mean wet cacao weight per pod for all the trees was 119 gms., while in June it was only 81 gms. At River Estate the decrease was from 124 gms. in January to 90 gms. in July, and at Ortinola there was a decrease from 119 gms. in January to 86 gms. in April, followed by a rise to 101 gms. in June.

Wet cacao weight thus shares the general progressive decrease previously noted for all pod dimensions. In 1931 the decrease was probably greater, for the June figures were generally lower than those of June 1932, but no January figures are available for comparison, as beans were not weighed at the commencement of 1931.

Analysis of Data.

The frequency distribution of mean wet cacao weight in the three plots under observation is illustrated in Fig. 4. The limits are roughly 45 and 165 gms.—a wide range. The modes occur at 95 and 100 gms. The River Estate pods have rather heavier contents than the Caura pods but in part this is due to the presence in the Caura population of a number of trees habitually producing curiously dry non-mucilaginous beans which are always very light.

On the assumption of an average loss in weight of about 60 per cent. on drying, wet cacao weight may be translated into "pods to the pound of dry cacao". This is done in Table 7. There are only two trees which with any certainty give pods of which seven or less will make a pound of dry cocoa. There are ten which produce pods eight to the pound. The majority require nine to thirteen, and several yield pods so small that more than twenty are necessary. These latter are not characterised by large beans or any other special properties, and are not worth their place in the cacao field.

The range of variability in mean bean weight is similar in all three plots (Fig. 5). There are few trees with characteristic bean weights below 2.0 gms., and few above 4.4 gms. The mode in each case occurs at 3.0 gms., and the majority of trees have beans within half a gramme of the

modal value, above or below. With a 60 per cent. loss in fermenting and drying, the average number of dry beans to the pound will be about 375, whilst in some cases there will be less than 250, and in others between 600 and 700.

In Table 8 the general constants of wet cacao weight are presented for the 20 best bearing trees on the three plots in the 1932 season. It is interesting to note that the general mean is the same for these good bearers as for the whole population, which shows that trees bearing large numbers of pods do not necessarily bear small ones. The variability within these trees is high, as shown by the standard deviation of the mean. The coefficient of variability averages 22 per cent.

The sample necessary to give a mean within five per cent. of the true mean is, in many cases, more than the total number of pods in the annual crop, a result to be anticipated from the introduction to this section. However, a sample of 30 pods is nearly always sufficient to give a mean within ten per cent. of the truth. Thus, a tree with a true mean yield of 150 gms. of wet cacao per pod will rarely be estimated by the standard sample at less than 135 or more than 165 gms. In practice the estimation will usually be much nearer the truth.

Table 9 gives similar statistics for mean bean weight. With certain variable factors removed, in particular number of beans per pod, the variability is naturally rather lower. The coefficient of variability is now only 17 per cent., and although in some cases nearly eighty pods would be necessary for an estimate of the mean within five per cent., twenty pods will usually give a figure within ten per cent., and the standard sample of thirty is safe to this level of precision.

Table 6.
ANALYSIS OF VARIANCE OF INDIVIDUAL BEAN WEIGHT.

Due to						D.F.	Sum of Squares.	Mean Square.
Between pods	..	..	..	..	..	9	5105.6	567.2
Between beans of a pod	..	..	..	..	..	34	677.2	19.9
Unexplained	..	..	..	..	..	306	3634.8	11.9
Total	..	..	..	..	..	349	9417.6	—

THE SIGNIFICANCE OF THE VARIANCE BETWEEN BEANS OF A POD.

Difference of $\frac{1}{2} \log_e$ values = .5142.

Difference to be significant is less than .2913.

Table 7.
PODS TO THE POUND.

Wet cacao wt. in gms.	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190
Pods to lb.	22.7	18.9	16.2	14.2	12.6	11.3	10.3	9.5	8.7	8.1	7.6	7.1	6.7	6.3	6.0

Table 8.
WET CACAO WEIGHT.

Trec.	2	39	85	79	6	227	1	154	232	188	10	45	33	62	13	53	51	98	92	72	Mean.
Mean ..	99.17	104.99	112.42	110.40	105.24	119.14	122.95	91.77	87.94	125.00	112.12	49.59	103.15	80.30	79.75	107.18	115.00	91.12	130.12	130.43	103.89
S.D. ..	24.10	21.49	31.54	24.12	22.88	22.49	31.53	18.86	24.63	31.01	21.00	12.00	22.02	21.05	17.93	26.65	23.26	15.36	24.35	23.41	22.98
C.V. ..	24.30	20.47	28.06	21.85	21.74	18.88	25.64	20.55	28.01	24.81	18.73	24.20	21.35	26.21	22.48	24.86	20.23	16.85	18.71	17.95	22.35
N 5 ..	94.48	67.04	125.97	76.38	75.62	57.02	105.18	67.57	125.54	98.48	56.13	93.70	72.93	109.92	80.85	98.88	65.47	45.42	56.00	51.52	81.20
N 10 ..	23.62	16.76	31.74	19.10	18.91	14.26	26.30	16.89	31.39	24.62	14.03	23.43	18.25	27.48	20.21	24.42	16.37	11.36	14.00	12.88	20.30

Table 9.
WEIGHT OF SINGLE BEAN.

Trec.	2	39	85	79	6	227	1	154	232	188	10	45	33	62	13	53	51	98	92	72	Mean.
Mean ..	2.72	3.23	4.25	3.17	3.24	3.50	3.00	2.74	2.68	2.83	3.11	1.37	3.12	3.06	2.37	3.47	3.26	2.66	3.75	3.90	3.07
S.D. ..	0.473	0.499	0.800	0.540	0.498	0.600	0.593	0.476	0.516	0.535	0.51	0.23	0.49	0.69	0.45	0.55	0.41	0.47	0.52	0.60	0.301
C.V. ..	17.39	15.45	18.82	17.03	15.37	17.14	19.77	17.37	19.25	18.90	16.40	16.79	15.71	22.55	18.99	15.85	12.58	17.67	13.87	15.38	17.12
N 5	48.38	38.19	56.67	46.40	37.79	47.01	62.53	48.27	59.30	57.15	43.02	45.10	39.49	81.36	57.66	40.19	25.31	49.95	30.78	37.84	47.67

5.—A Comparison of the Seasons 1931 and 1932.

The preliminary analysis of the crop of the three plots in the Northern Range was repeated in 1932 with two objects in view. The first was to measure the effect of different seasons on the several pod statistics examined, and the second to check the technique and sampling constants estimated in the first year.

Weather.

The weather of the two years was very different, and for the purpose of comparison this was fortunate, for the effects, if any, should be all the clearer. The rainfall chart for River Estate (Fig. 6) shows that the first half of 1931 was much drier than 1932, while the "wet months" of 1931 were extremely wet. The rain during the latter part of 1931 had a very pronounced effect on fruit setting and wilting of the 1932 crop. In some districts the effect was felt more directly, for the excessive rains caused heavy losses of nearly mature pods. Thus in 1932 the early crop vanished almost entirely and there was no big harvest in January and February. The early crop is usually a trunk crop, and it was noticeable in 1932 that there was very little trunk crop. The branch crop, however, was good in March and April.

This fact would lead to the anticipation that the pod dimensions in 1932 would be slightly lower than those in 1931.

Total Crop.

The total number of pods harvested from each plot during the two seasons is given in Table 10. In December 1930 the first picking of the 1931 crop was missed on all plots.

Table 10.

TOTAL PODS ON THREE PLOTS.

		1930-31.	1931-32.
Caura	.. ..	3,956	2,457
River	.. ..	2,528	2,622
Ortinola	.. ..	3,438	2,370

From Caura and Ortinola the crop was very much smaller during the second year, but at River Estate it was slightly larger. The graphs showing intensity of harvest on each plot in the two years demonstrate that it was not until February when the 1932 crop overtook the 1931 crop. The minor crops were much the same in both years on all plots. These graphs show very strikingly where the difference in the total crops was felt and emphasize the ill effect of unfavourable conditions during the growing period. (Figs. 7, 8 and 9).

It is rather curious that the Caura and River graphs are very much alike, but the Ortinola plot in both years produced nearly all its crop in a very short space of time.

As regards individual trees, it was evident that the majority were either comparatively good bearers in both years or relatively poor in both, only a few being good in one year and poor in the other. No figures are necessary to demonstrate this point, as it is entirely in keeping with the conclusions arrived at by the Trinidad Department of Agriculture some years ago, and demonstrated fully in the publications of that Department.

The relation between yield and age (or size) which was found for the Caura population in 1931 was the same in 1932, showing that in the main the trees preserved their relative capacities to yield in both years.

Class.	No. Trees.	Average Yield per Tree.	
		1931.	1932.
Very young	11	0.1	0.1
Young	15	10.3	9.2
Old	61	41.5	25.8
Very old	15	87.5	59.5

Pod Statistics.

1. *The trend within a season.*—From the 1931 crop it was shown that as the season advanced from January to June, there was a very significant decrease in pod dimensions on the same tree. On account of the generally larger crop in 1931 it was possible to demonstrate this fact statistically on several trees, but in 1932, with the poorer crop, some of these trees did not give ripe pods at each picking. However, the average of the mean pod dimensions for each harvest in 1932 shows a decrease in mean pod length of between five and ten per cent., and for diameter about ten per cent. This corresponds favourably with the figures for 1931.

Except in the case of Caura, 1932, where a large decrease occurs, the decrease in bean number is of the order of five per cent. For wet cacao weight in the second year the decrease from January to June was about 30 per cent. Since in the corresponding harvest in June, 1931, the characteristic wet cacao weight was rather lower, we may assume the decrease during 1931 was not less than in 1932. The decrease in shell thickness in the second season was between 10 and 20 per cent., which is rather greater than in 1931.

Thus the decrease in all pod dimensions within one season was very similar in both years. What proportion of this is actually correlated with time of year and how much with a relegation of later pods from the main to the finer branches, is not yet clear. In a distinct set of measurements (2)

(2) Those used for "Note on the Progeny of a Single Cacao Tree."

a very definite relationship was found between pod dimensions and number of pods harvested. Table 11 shows the mean dimensions at each of

Table 11.

SEASONAL CORRELATION BETWEEN CROP AND SIZE OF POD.

Date.	23rd Jan.	22nd Feb.	9th Mar.	15th April.	17th May.
Crop in pods ..	155	107	85	152	140
Length ..	13.8	13.1	12.8	13.5	13.0
Diameter ..	7.4	7.1	6.9	7.2	6.8
Thickness ..	1.3	1.2	1.2	1.3	1.2
No. of beans ..	29	28	28	29	26
Wet cacao wt. ..	79	70	70	71	65
Single bean wt.	2.7	2.4	2.5	2.4	2.4

five consecutive pickings from twenty trees which gave a good harvest on each occasion, compared with the number of pods picked. The crop decreases from January to March, returns in April to its January level, and decreases again in May. The January and April crops in this case correspond roughly to the major and minor crops, though for this particular block of trees in 1932 they were alike. The trend in all pod dimensions except mean bean weight follows the trend in crop, so that when the trees are producing many pods they are also producing larger pods than when they are carrying few. The statistical correlation is positive and appreciable in all cases, but only for pod length would it occur by chance less than once in a hundred trials.

2. *The Mean Pod Dimensions.*—For the dimension of length, the frequency curves are again very similar and in the same relative order. A comparison of the two years is expressed by a frequency curve of differences (1931 values minus 1932 values for the same trees) (Fig. 10). The mode occurs very distinctly at 3 mms. in favour of the 1932 crop, and the curve descends very symmetrically on both sides. The maximum deviations are large and call for comment. It was shown from the 1931 crop that a sample of between 20 and 30 pods was necessary to give a value for the mean within 5 per cent. ninety-five times out of one hundred trials. The maximum error in comparing the two years must then be about 10 per cent. Taking a working mean of 16 cms. for the three plots, the 10 per cent. deviation lines have been marked in the graph, and it is very obvious that a good number of deviations exceed this value. However, by using figures from only those trees which gave adequate samples in both years, the limits of the frequency curve are brought well within the 10 per cent. ordinates and very few fall outside the 5 per cent. values. This demonstrates the accuracy of the sampling constants calculated from the 1931 crop, and shows further that it is not safe to characterise a tree from a small sample of pods.

In the case of diameter, the mode-deviation occurs 1 mm. in favour of the 1932 crop. The curves of total samples and adequate samples are very symmetrical about the mode and the limits of the adequate samples curve fall almost exactly at the 10 per cent. deviation values (Fig. 11).

It was pointed out in Section 2 that shell thickness was more variable than either length or diameter, that a sample of 30 pods was usually sufficient to characterise the tree to within five per cent. of the mean, but in some cases more pods would be necessary. The curve for adequate samples (Fig. 12), cuts the ten per cent. ordinates at an appreciable value, showing that the conclusions with regard to sampling numbers for shell thickness were correct. The deviation curves in this case are fairly symmetrical about zero, showing that no seasonal difference could be detected in thickness.

The case of bean number further illustrates this point. Here it was decided the variability was so great that no convenient sampling number could be obtained at all with a precision within five per cent. Taking trees which produce 30 or more pods in each year, the deviations of the means form a frequency curve whose limits extend far beyond the ten per cent. ordinates (Fig. 13).

The mode of these samples occurs at zero, showing that there is no seasonal effect on bean number when good bearing trees are concerned. The total sample curve, however, shows a mode of one bean per pod in favour of the 1931 crop. Bearing in mind that a large percentage of the 1932 crop was a branch crop, this fact appears in favour of the suggestion that branch pods showed a tendency for fewer beans than trunk pods (Section 3). The zero mode for good bearers suggests that in both years these trees produced a well distributed crop.

Sampling Constants.

Sampling constants have been calculated for the twenty best trees in 1932 from the three plots. In general, the figures were very similar to the constants for the ten best bearers at Caura in 1931, and for economy of space only the extreme and mean values are presented in Table 12. The comparison is more concisely brought out in Table 13, which gives the average mean and standard deviation for the two years. In 1932 the variability tended to be rather less than in 1931. This may be due to the absence of the main crop in January of the latter year.

Summary of Effect of Season.

The greatest effect is seen in the number of pods borne by the tree. In 1932 the greater part of the early crop was lost through excessive wilting during the late months of 1931.

In the case of dimensions, there was a slight decrease expected but a slight increase was obtained. In the case of pod length, the mode

Table 12.
SAMPLING CONSTANTS FOR TWENTY BEST
TREES, 1932.
Pod Length.

		Tree with		Mean of Total.
		Min. "N"	Max. "N"	
Mean	..	15.50	13.74	15.68
S.D.	..	1.134	1.770	1.487
C.V.	..	7.31	12.88	9.51
N.	..	8.55	26.54	14.71

Pod Diameter.

		Tree with		Mean of Total.
		Min. "N"	Max. "N"	
Mean	..	7.10	7.65	7.66
S.D.	..	0.431	0.952	0.670
C.V.	..	6.07	12.44	8.71
N.	..	5.89	24.75	12.49

Shell Thickness.

		Tree with		Mean of Total.
		Min. "N"	Max. "N"	
Mean	..	1.15	1.27	1.36
S.D.	..	0.146	0.224	0.207
C.V.	..	12.70	17.64	15.10
N.	..	25.81	49.79	36.73

Number of Beans.

		Tree with		Mean of Total.
		Min. "N"	Max. "N"	
Mean	..	33.93	25.94	33.72
S.D.	..	3.22	7.85	5.61
C.V.	..	9.48	30.26	16.95
N.	..	14.38	146.51	49.90

increase was of the order of two per cent., and adding to this the possible effect of a branch crop, the increase would hardly be more than five per cent.

In diameter the mode increase is less than two per cent., and in shell thickness no difference could be demonstrated. Thus, as far as dimensions go, the effect of a wet season and a smaller crop is to cause a slight increase in pod size, but so slight that for our calculations it could be neglected.

In the case of bean number from good bearing trees there appears to be no effect attributable to season.

It is unfortunate that there are no figures for comparison of wet cacao weights and bean weights, but if the pods themselves are not appreciably larger there cannot be a very pronounced increase in the size of the contents.

6.—Summarised Results of the Quantitative Survey.

With sample size definitely ascertained from intensive study of three blocks of 100 trees each, as reported in the foregoing sections, the investigation of pod constants was extended to include a larger sample of Trinidad cacao.

On the map of the island shown in Fig. 14, the stations where trees were examined are indicated. Thus, in the Northern Range there were three stations from which five plots were examined. In the Central Range there were three stations and four plots. In the Southern Range there were two stations and three plots. At each station a block of trees which had not been harvested for several weeks was reserved for examination. Those trees which had sufficient ripe pods at the time for a sample were labelled and the pods examined in detail. No other "selection" was made and the trees sampled at each station may be regarded as a random sample of that particular population, with the one reservation.

It may here be noted that the planting of Trinitario cacao in Trinidad was first confined to the Northern Range, where it was introduced by the Spaniards. The long fertile valleys, well sheltered from prevailing winds, proved an ideal home for this crop. In course of time it spread southwards to the Central Range, where very large areas eventually became devoted to it. The Southern Range was only planted with cacao within very recent times. A complete account of the history and distribution of the crop in Trinidad has recently been compiled by Shephard (3).

The newer areas seem to be producing better cacao than the older ones. Most of the large-beaned trees found in the course of the survey came from the Central and Southern Ranges. As the distribution of type, discussed in a later section, does not indicate a preponderance of any particular "varieties" in the newer areas,

(3) Shephard, C. Y. "The Cacao Industry of Trinidad." *Tropical Agriculture*, IX, 1932.

the difference is presumably largely one of soil fertility, connected with the length of time cacao has been growing in the different areas. In support of this, at the estate of La Vega in the Central Range, an old field near the river gave a very inferior sample compared with that of a much more recently planted field a short distance away.

The total number of trees examined was 950, and frequency curves have been constructed from the combined data which, taking into account the composite nature of the sample, are believed to represent the range of variability in the Trinitario complex with a reasonable degree of accuracy.

The range for pod length as illustrated in Fig. 15, extends from 10.5 cms. to 23.5 cms. The mode occurs almost exactly at 16.0 cms., the curve slopes steeply on either side and is fairly symmetrical. There is no suggestion of a break in the curve or of a second maximum.

The frequency curve for diameter (Fig. 16) is also fairly symmetrical, ranging from 6.1 cms. to 10.6 cms. and rising steeply to a maximum at 8 cms.

The pod ratio, or shape, curve shows that on the whole length is positively correlated with diameter, and the frequency curve shows a steep approach to and from a mode of 1.95. This is illustrated in Fig. 17. It is worth noting that the tendency to bimodality found in the smaller sample last year has disappeared in the larger sample, as was partially anticipated (1931 Report, pp. 16 and 17).

Thus, for mean pod dimensions this sample of the complex shows that the mixing of types is very fine, that the whole complex may be regarded as one population, and that the sample must have been a representative one.

This fact is also brought out in shell thickness, where the frequency curve ranges from 0.8 to 2.4 cms., with a mode at 1.4 cms. (Fig. 18).

The bean number curve (Fig. 19) shows a mode between 34 and 35 beans per pod. It is interesting that the number of beans commonly said to be characteristic of Calabacillo types is 40 and the number for Criollo 30 per pod. The intermediate mean for the whole population tends to support the suggested origin of the complex. The bean number curve is not symmetrical, since the upper limit is 45 and the lower part tails to 15. This asymmetry is presumably caused by factors which prevent the development of the total number of ovules in a pod.

The frequency curve for wet cacao weight is not presented as such. Using the fact that there is a loss of about 60 per cent. during the fermenting and drying processes, the statistic has been translated into "Pods to the Pound (Dry Cacao)". This makes a more comprehensive graph for the practical planter (Fig. 20).

The statistic of wet cacao weight is evidently very variable, and it must depend on environmental conditions to a large extent. In a field where trees are moss-covered and moribund it is easy to see that the beans weigh less than those from a field where the trees are healthy and vigorous. The fields used in the survey were generally of the latter type and rather better than the average, because a good crop was essential for sampling. This should not affect the limits of variability to a very great extent but the mode will be slightly biased.

The range extends from six to more than twenty pods to the pound. The mode appears at ten, but this may be low for the reason advanced above. The curve is very obviously asymmetrical, showing that there are a good number of trees which require more than fourteen pods to the pound. Even with this asymmetry there is no suggestion of more than one population within the complex.

Table 13.

COMPARISON OF VARIABILITIES.

YEAR.				LENGTH.		DIAMETER.		THICKNESS.		BEAN NUMBER.	
				Mean.	S.D.	Mean.	S.D.	Mean.	S.D.	Mean.	S.D.
1931	..	..	..	15.38	1.67	8.06	0.78	1.64	0.27	33.03	7.06
1932	..	..	..	15.68	1.49	7.66	0.67	1.36	0.21	33.72	5.61

The average weight of a single bean from each of the trees sampled gives the frequency curve shown in Fig. 21. The range of variability is

Table 14.

Dimension.	Lower Limit.	Upper Limit.	Mode.
Length ..	10.5 cms.	23.5 cms.	16.0 cms.
Diameter ..	6.1 cms.	10.6 cms.	8.0 cms.
Ratio (Shape) ..	1.3	2.7	1.95
Shell thickness ..	0.8 cms.	2.4 cms.	1.4 cms.
No. beans ..	15	45	34.5
Pods to the pound	6	22	10.5
Wt. of a single bean ..	1.1 gms.	5.6 gms.	3.2 gms.

large, extending from 1.1 to 5.6 gms. The mode occurs at about 3.2 gms., but may be a trifle high for the reason given above.

Table 14 summarises the range of variability of all the characters examined. In every case the inter-grading is so fine that the complex may be looked upon as a single population.

The data summarised in this table provide a sufficient basis for selection, and with its presentation the preliminary survey of quantitative characters is completed, for it is unlikely that further measurements of the same kind would add anything material to our knowledge of the complex, and attention must now be turned more directly to the actual procedure of selection.

7.—The Classification and Distribution of Type.

The extreme variability of Forastero cacao as exhibited in the group called "Trinitario", has been discussed by many authors, and summarized recently by Cheesman (4), who adopts as a working hypothesis Pittier's view that the group represents a series of hybrids between at least two originally distinct species. All who have dealt with the subject have recognized within the complex a number of "types", which, however, are interconnected by transitional forms, so that the "varietal" names applied (Angoleta, Cundeamor, Amelonado, Calabacillo and so on) are merely terms of convenience which indicate approximate positions on a continuous series of variability.

The "types" are in every case based on pod characters, and since these characters must have a genetic foundation, it would appear reasonable to suppose that some "types" might prove inherently better yielders than others, even though the distribution of quantitative characters shows perfectly continuous variation throughout the whole population. In other words, it might be possible to correlate "type" with characters contributing to yield, and to concentrate the search for high yielding trees on to that section of the population showing certain qualitative characters.

As a first step in the investigation of such correlations it becomes necessary to define the type, and for this purpose the existing classification is insufficiently precise. It has been found more useful for the purposes of this survey to assign to each tree a position on a map of which the ordinates represent components of pod shape and surface texture and the abscissae components of pod pigmentation. It is possible to recognize five classes of shape, two of surface texture, and eleven of colour, so that the whole of the Trinitario complex can be sorted into one hundred and ten different types. This classification is admittedly still imperfect, and particularly in the case of the colour divisions a number of borderline cases are continually being met. Strictly, of

course, it is impossible to classify the members of a continuous series except by arbitrary divisions, and in such cases the greater the number of divisions the greater the precision. Herein lies the advantage of the system adopted over the older classification, which recognized only a very few ill-defined groups.

It will be shown that in the end the same types tend to come together in either classification, showing that both have fundamentally a natural basis in relationships.

Shape.

The shape types depend in the first place on the presence or absence of a constriction at the stalk end, typical of Cundeamor and commonly known as a bottle-neck, and secondly on the character of the apex, which may be long-pointed or not. This made four possible classes, as follows:—

- A.—With both bottle-neck and long point.
- B.—With bottle-neck but without long point.
- C.—Without bottle-neck but with long point.
- D.—Without either bottle-neck or long point (*i.e.*, oval).

Class D. was again divided into:—

- D1.—Long oval pods.
- D2.—Short oval pods.

At first this distinction was judged by eye, but it appeared on subsequent analysis that the dividing line always came approximately at a ratio of length to diameter of 1.6. After that discovery the eye estimation was replaced by actual measurement.

Each of the five shape classes were sub-divided into two, depending on the degree of wartiness of the surface. This made the ten classes for shape and surface texture. For shape alone the judging of two plus or minus factors was not difficult. The long point was always distinctly long, otherwise it was classed as absent. In cases where there was a smooth apex with no point at all, the trees generally fell automatically into the "short oval" class.

(4) Cheesman, E. E. "The Economic Botany of Cacao." Suppt., *Trop. Agriculture*, June, 1932.

Some difficulty was experienced at first over the character for wartiness. The true Criollo pod is warty (except the curious Porcelaine variety) and so is the Alligator. The Calabacillo is perfectly smooth. It is easy to distinguish between true Criollo and Calabacillo on this character, but the Angoletas and Cundeamors are not so well defined. In practice only if the surface was very rough were the pods classed as "warty". A decision was often helped by the very obvious fact that warty pods usually have deep furrows. In order not to complicate the map too much, no classification of ridges and furrows was made. Most types possess ten ridges, but there are a few with only five.

The bottle-necked types will correspond more or less to the old Cundeamor, the long warty types without constriction will generally be Angoletas, the long oval smooth and some of the short oval smooth types will be Amelonados, and the remainder of the short oval smooth types will be Calabacillo.

Colour.

Ripe pods can usually be classed as red or yellow. This was the criterion for the older divisions when colour was taken into account at all, but in practice it is by no means adequate.

There seem to be two basic colours for pods of the Trinitario complex, namely green and light green (called herein "white"). Although the morphological differences are not yet clear, it appears that in the green class the chlorophyll-containing tissue extends to the epidermis, while in the white pods there are several layers of colourless cells interposed between the chlorophyllous tissue and the surface. There is also a type intermediate between the two, which is white in the furrows and green on the ridges, but it is not common.

The majority of pods also show more or less red pigment. This seems to be caused by the presence of a red cell sap in the epidermal cells and sometimes those just below. The red pigment must be governed by several determinants, for there is a perfect series of types, from pods just flecked with red to pods completely red. The series is found on both green base and white base pods, and its completeness is due to the fact that light appears to play some role in the expression of colour. Thus pods which are partially red at a height of six to ten feet may be rather more heavily pigmented low on the trunk and much less pigmented high among the foliage.

Salient points which may correspond to gene composition seem to occur as follows:—

1. The completely non-red pods.
2. Pods with "splashes of red pigment".
3. The partially coloured pods.
4. The "white or green in furrows" pods.
5. The completely pigmented pods.

The limits of each of these colour classes will be discussed briefly.

1. *The completely non-red pods.*—Both white and green pods occur with no obvious pigment. They are common to nearly all shape classes, both warty and smooth. In the field they are perfectly distinguishable and the shade of colour does not vary much. In the type which combines both basic colours, sections of the outer tissues show that in the furrows the chlorophyll tissue does not reach the surface but on the ridges it does. These types are represented in Plate I,* Figs. 1-3.

2. *Pods with "splashes of red pigment".*—Plate II, Figs. 4 and 5, illustrate what is meant by the term "splashes" of pigment. It is the lowest grade of pigmentation. There is rarely any pigment at all in the furrows, but on some or all of the ridges there are small isolated patches which are red. In some cases very little pigment is present and it disappears even before the pod starts to ripen. The type is common to both white and green bases and the pods ripen yellow indistinguishable from the ripe pods of the first class.

3. *The partially coloured pods.*—This is the centre class and has rather wide limits. It bounds the "splashes of red" type with a pod which shows continuous red on the outer ridges, often descending to the furrows, and extends to types which have continuous red on all ridges, and in the outer furrows.

These extremes of type may occur on the same tree. Pods which are exposed generally show more pigment than those which are hidden by the foliage, trunk pods naturally being redder than those from the branches.

The basic colours can always be easily distinguished on the underneath side of the pod (Plate II, Figs. 6 and 7).

4. *The "white or green in furrows" type.*—On an ascending scale of pigmentation this is the last class where the basic colours can be distinguished directly. There seem to be two types included, but the actual degree of pigmentation is much the same in both, so that the number of red colour factors is probably very similar.

One sub-type is the tree on which the pods are deeply furrowed and the basic colour can be seen in most of the furrows. When it is "white" it is often pure white, showing there may be very little chlorophyllous tissue beneath.

The other sub-type is not so deeply furrowed and the basic colour can only be examined from the rear furrows. Some of the pods on such trees may be almost completely red.

The type is illustrated by Figs. 8 and 9, Plate III.

5. *The completely red pods.*—The remaining types are those in which no basic colour can be examined directly, since the pigment extends

* See Frontispiece.

completely over the pod. Division into two types was made on an indirect estimation which may not be absolutely correct.

In the previous class where actual basic colours can be seen, the reds on the different bases are quite distinguishable. Where the basic colour is white the red is bright or crimson. When the basic colour is green the red is very dark and from a distance appears purplish. This difference in colour may not be due entirely to differences in base but may also be caused by stronger doses of pigment. For present purposes trees of this class were considered to belong to the white base series if the red colour was not too dark or merely crimson, and to the green base series if the red was very dark, purplish or almost black (Plate III, Figs. 10 and 11).

Classes 1 and 2 ripen yellow, whether the basic colour is green or white. With a little practice it is possible to distinguish the yellows of the two bases. White pods ripen to a primrose type of yellow, while green pods ripen to a deeper hue.

Classes 4 and 5 ripen red. There is a good deal of variation between the different hues of red, since the pigment disintegrates during ripening. Over-ripe pods may even be orange in colour.

The pods of class 3 ripen to a pale orange colour which is about mid-way between the others. The depth of colour depends on the amount of red pigment to a large extent.

Distribution of Type.

The general distribution of type over the 950 trees measured in the quantitative survey is shown in Table 15, filled in upon the complete type map.

In addition, two blocks of trees at River Estate were classified for type. The first consists of 693 trees in a field planted in 1914, and therefore all 18 years old or less; the second consists of 482 bearing trees from a much older field, some of the trees in which may be parents of the trees in the younger field.

The distribution of shape alone in the three sets of trees is set out in Table 16, where the figures given are reduced to percentages in order that the columns may be directly comparable.

The similarity between the three distributions is much more striking than the relatively minor differences. Roughly speaking, the oval types in each case account for 80 per cent. of the trees, the long oval being more than twice as numerous as the short.

The distinction between warty and smooth has been omitted from the table for simplicity, but the total figures are:—Block I, 359 smooth, 334 warty; Block II, 239 smooth, 243 warty; General Survey, 598 smooth, 352 warty. In this respect, therefore, there is a considerable difference between the River Estate trees and the composite sample from other parts of the country, but in all the features of shape, as distinct from surface, the correspondence is fairly close, the distribution of the composite sample lying between

those of the two River Estate blocks. As the River Estate trees together number 1,175, and the survey trees 950, the result may be taken to indicate that a sample of 1,000 trees exhibits a fair approximation to the distribution of shape in the whole population.

The distribution with respect to colour is similarly set out in Table 17. For basic colours it is almost identical in the three cases, and even between the individual classes, where the numbers are in some cases inevitably small, it is satisfactorily close. The analysis by colour, in fact, supports the conclusion from the analysis by shape, that the mixing of genetic types in the Trinitario complex is sufficiently thorough for a random sample of 1,000 trees to represent the whole population with practical usefulness.

Possible Dominant Factors in Cacao.

From the distribution of type, indications may be obtained of genetic factors, or groups of factors, which are probably Mendelian dominants, and with the possibility of future breeding operations in mind, it is of interest to tabulate some of these indications.

Shape.—In the type distribution maps the trees which have pods with modified ends, *i.e.*, long point and/or bottle-neck total about one quarter of the whole population. Assuming that the complex is as thoroughly mixed as it appears from the type distribution, it seems evident that factors which produce modifications of the end of the pod are recessive.

Length and diameter.—The short oval pods total about one quarter of the whole, and as pods with modified ends are usually relatively long, long pod seems to be dominant to short pod. The genetic importance of the pods with modified ends seems to be connected with the spacing of ovules on the placenta, and a bottle-necked pod may be the result of a combination between two series of factors, one for length of pod (Criollo) and the other for bunching of ovules (Calabacillo).

Basic colour.—Basically white types are more numerous than basically green. There is some evidence to suggest that the latter are more susceptible to infections of *Phytophthora faberi* (Black Pod) than the former, and the difference in quantity distribution may be a result of natural selection.

Pod pigment.—With regard to colour, Harland and Frecheville (5) have shown that the red pigment of pods is in some way associated with the presence of a little pigment at the base of the petiole, called by them "axil spot." The factors which govern this pigment are dominant. However, there must be a series of factors responsible for pod colour, for these authors mention that trees showing no axil spot may have some red pigment in the pods.

(5) Harland, S. C. and Frecheville, G. E.—"Natural crossing and the genetics of aril spot in cacao." *Genetica*, IX (1927), 279-88.

Table 15.

GENERAL DISTRIBUTION OF TYPE IN SURVEY.

		GREEN BASE.						WHITE BASE.							
		Very Dark Red.	Green in Furrows.	Partially Red on Green.	Splashes of Red on Green.	Green.	Green-White.	White.	Splashes of Red on White.	Partially Red on White.	White in Furrows.	Dark or Crimson Red.			
Bottle-neck, long pt., warty	..	3	3	0	1	3	0	12	3	4	3	1	33	45	
Bottle-neck, long pt., smooth	..	1	0	0	1	3	1	1	1	1	2	1	12		
Bottle-neck, blunt pt., warty	..	1	1	1	0	0	2	8	2	5	0	0	20	36	
Bottle-neck, blunt pt., smooth	..	0	0	2	0	2	3	3	1	4	0	1	16		
Long pt., warty	..	2	6	7	4	5	1	7	1	2	1	5	41	81	
Long pt., smooth	..	4	6	3	4	1	0	6	3	7	2	4	40		
Long oval, warty	..	7	21	21	10	33	14	39	28	33	15	5	226	552	
Long oval, smooth	..	16	18	54	19	37	11	45	28	71	14	13	326		
Short oval, warty	..	1	1	2	0	2	1	12	7	4	2	0	32	236	
Short oval, smooth	..	6	4	27	15	15	12	36	24	51	6	8	204		
Total	..	41	60	117	54	101	45	169	98	182	45	38			
						373	45						532		

Table 16.

THE DISTRIBUTION OF SHAPE.

(IN PERCENTAGES.)

	River Estate. 693 Young Trees.				River Estate. 482 Old Trees.				General Survey. 950 Trees.			
Bottle-neck, point ..	..	..	..	7.1	22.5	2.9	14.4	4.7	17.0	3.8	8.5	58.1
Bottle-neck, no point ..	..	..	..	7.2		6.8		3.8		8.5		24.9
Long point ..	..	..	..	8.2		4.7		58.1		24.9		
Long oval ..	..	..	..	51.7		62.0						
Short oval ..	..	..	..	25.8		23.5						

Wartiness.—The number of “warty” pods generally equalled the total of those “just warty” and “smooth,” so that complete smoothness of pods is probably recessive to wartiness.

Bean number.—It is generally recognized that pure line strains of Criollo cacao usually contain fewer beans per pod than the hardier varieties. This may not be so with regard to ovule number, for the writer has shown (6) that ovule number seems to be independent of shape but that a greater percentage of ovules fail to reach maturity

in Angoleta pods than in Amelonados. If lethal factors are responsible, they must, of course, be recessive.

Bean pigment.—It is quite obvious that pigment in beans is generally dominant to no pigment.

General.—On general grounds it appears that in the complex the external pod characters which are associated with Criollo or Alligator are more often expressed than those typical of Calabacillo, but that in bean features the reverse is the case.

8.—Correlations between Type and Quantitative Characters.

Type and number of pods per annum.—When it was discovered that the distribution of type in a certain field at River Estate runs closely parallel to the distribution in the composite sample of trees dealt with in the quantitative survey, an interesting investigation of correlation with bearing was made possible. For most of the survey trees, the yield in pods is not known, owing to the shortness of time observations have been in progress, but the River Estate trees have been individually recorded since they came into bearing. Furthermore, they are all eighteen years old or less, so that the variability introduced by the age factor in older fields is largely eliminated. For permission to use the yield records we are deeply indebted to the Trinidad Department of Agriculture.

(6) Pound, F. J. First Annual Report on Cacao Research, p. 22 *et seq.*

The mean annual yield per tree over the five-year period 1927-31 is entered in Table 18 for all the shape and colour classes represented in the block of 693 young trees mentioned in the foregoing section. The general means for colour and shape given in Table 11 are the means of all the trees represented in the particular row or column of the table, and not the average of the means entered in the squares.

It is evident that there can be very little correlation between yield in pods and shape. It looks suggestive that the trees producing bottle-necked pods with a long point are rather more productive than the others. There is, however, a very suggestive distinction between warty and non-warty types, the latter in every case producing on the average more pods than the former. Referring to the supposed ancestry of warty and

Table 17.

THE DISTRIBUTION OF COLOUR.

(IN PERCENTAGES.)

GREEN BASE.							WHITE BASE.						
			Very Dark Red.	Green in Furrows.	Partially Red on Green.	Splashes of Red on Green.	Green.	Green-White.	White.	Splashes of Red on White.	Partially Red on White.	White in Furrows.	Dark or Crimson Red.
River Estate	}	.. ..	4.2	5.9	11.5	3.8	11.0	5.8	21.1	9.1	15.0	6.8	5.9
693 Young Trees			36.4						57.9				
River Estate	}	.. ..	1.6	4.1	17.4	7.3	9.1	4.6	11.8	8.5	25.3	5.2	5.0
482 Old Trees			39.5						55.8				
General Survey	}	.. ..	4.3	6.3	12.3	5.7	10.6	4.7	17.8	10.3	19.2	4.7	4.0
950 Trees ..			39.2						56.0				

smooth types, this fact supports the general opinion that Calabacillo types of tree produce more pods than Criollo, and the smooth-skinned types of the table undoubtedly have more Calabacillo genes in their constitution than the warty types.

A very curious feature comes out in colour classes. Broadly, there is no distinction between white base and green base, but the long oval green-white types seem to be very productive. In the case of green base pod types the extremes of pigmentation go with a big yield, in the white base series exactly the reverse is the case, and the partially coloured types seem to be more productive.

A further point was needed from the yield records, namely, is there a correlation between type and the number of good bearing trees? As an arbitrary figure, a yield of 60 pods per annum was taken to be the criterion for distinguishing good bearing from other trees. On this basis approximately 20 per cent. of the trees are good bearers. Table 19 shows their distribution in the

type map. Dealing first with shape, from the totals of the three broad classes the proportion of the whole which may be classed as good is practically the same in each, namely 20.5 per cent., 19.3 per cent., and 17.9 per cent. It is indecisive whether the smooth types have more good bearers than the warty types, and shape on the whole does not seem to be linked with bearing capacity. In the case of basic colours, there is no significant difference between green or white base, but the green-white types have more than the average number of good bearers. Thus, for good bearing one must look rather for individual trees than for a particular type which will always fulfil this condition. Suggestive correlations which may be useful for breeding work are, however, apparent.

Shape and pod dimensions.—From the definition of shape, there must be correlations between the qualitative classes and pod length or diameter, and such scarcely merit comment. In the case of shell thickness (measured through the ridges), it is worth noting that thick shell occurs with a long point and the thin shell with the bottle-neck constriction. Pods with a bottle-neck and long

Table 18.

MEAN YIELD PER TREE.

	GREEN BASE.						WHITE BASE.					
	Very Dark Red.	Green in Furrows.	Partially Red on Green.	Splashes of Red on Green.	Green.		Green-White.	White.	Splashes of Red on White.	Partially Red on White.	White in Furrows.	Dark or Crimson Red.
Bottle-neck, long pt., warty ..	0	45	79	60	42	0	27	23	47	24	73	42
Bottle-neck, long pt., smooth ..	23	67	0	107	14	0	37	0	60	0	18	45
Bottle-neck, blunt pt., warty ..	0	34	43	21	43	0	29	16	39	46	0	34
Bottle-neck, blunt pt., smooth ..	0	0	34	42	25	11	39	53	54	0	0	36
Long pt., warty ..	19	36	35	39	41	0	21	23	33	32	61	33
Long pt., smooth ..	0	50	33	0	6	0	0	26	125	31	61	46
Long oval, warty ..	79	40	28	22	39	57	33	36	35	38	25	37
Long oval, smooth ..	42	27	34	40	44	54	34	40	39	51	41	40
Short oval, warty ..	11	43	30	0	36	27	47	35	41	46	19	37
Short oval, smooth ..	38	0	41	44	51	37	37	42	41	14	42	40
Mean ..	47	38	35	41	41	47	34	34	41	37	41	
	39					47	37					

point have thinner shells than those with only a long point. The long oval types have thicker shells than the short oval types (Table 20).

Another interesting correlation comes out in the feature of wartiness. For pod length, diameter, and shell thickness, the warty pods of each class have greater dimensions than the smooth pods.

Shape and bean number.—Low bean numbers occur rather more frequently with long-pointed types than with others, but the correspondence is not very pronounced, and in general there is slight variation in bean number with shape.

Shape and wet cacao weight.—On the average, long oval pods have the heaviest contents and long-pointed pods without bottle-neck the lightest. Warty and smooth types again show a general difference, the average weight per pod in warty classes being 122 gms. and in smooth classes 116 gms. On the other hand, both high and low wet cacao weights occur in all shape classes.

Shape and bean weight.—The heaviest beans occur in the pods with bottle-neck and long point, and long oval types also have large beans. Warty pods again usually have heavier individual beans than smooth, but the difference is too slight to have much value.

Colour and dimensions.—There is no apparent difference in any dimension between pods of the green base series and those of the white base series, taken as a whole, but the "green-white" types are almost invariably smaller than either. Within both series there is a general tendency for pods classed as "partially red" to have smaller dimensions than either those with little or no red pigment or those with full or almost full pigmentation (Table 21). This is partly explained by the fact that a large proportion of "partially red" pods occur in the "short oval" shape class, connected with which is another fact that the correlation is less marked with diameter than with length. Table 22 shows the distribution of mean

Table 19.

GOOD BEARERS.

		GREEN BASE.					WHITE BASE.							
		Very Dark Red.	Green in Furrows.	Partially Red on Green.	Splashes of Red on Green.	Green.	Green-White.	White.	Splashes of Red on White.	Partially Red on White.	White in Furrows.	Dark or Crimson Red.	Total.	
Bottle-neck, long pt., warty	..	0	0	1	2	0	0	1	0	2	0	3	9	13
Bottle-neck, long pt., smooth	..	0	1	0	1	0	0	1	0	1	0	0	4	
Bottle-neck, blunt pt., warty	..	0	0	1	0	1	0	2	0	0	1	0	5	8
Bottle-neck, blunt pt., smooth	..	0	0	0	0	0	0	2	0	1	0	0	3	
Long pt., warty	..	0	3	0	0	2	0	0	0	0	1	1	7	11
Long pt., smooth	..	0	1	0	0	0	0	0	0	1	0	1	4	
Long oval, warty	..	0	4	1	1	2	5	5	6	3	4	0	31	69
Long oval, smooth	..	2	0	5	1	6	8	5	3	4	1	3	38	
Short oval, warty	..	0	1	0	0	0	1	1	2	1	1	0	7	32
Short oval, smooth	..	0	0	4	0	3	2	6	1	7	0	2	25	
Total..	..	2	10	12	5	14	16	23	12	20	8	10		
		43=11.5%					16=35.5%	83=15.6%						

Table 20.
CORRELATIONS BETWEEN DIMENSIONS AND SHAPE.

			Mean Length.	Diameter.	Shell Thickness.	Wet Cacao Weight.	Number of Beans.	Single Bean Weight.
Bottle-neck, long pt., warty	..		19.3	8.2	1.52	121	34.0	3.6
Bottle-neck, long pt., smooth	..		17.7	8.1	1.42	119	34.0	3.5
Bottle-neck, blunt pt., warty	..		16.7	7.8	1.27	126	36.0	3.5
Bottle-neck, blunt pt., smooth	..		15.1	7.7	1.28	108	34.5	3.2
Long pt., warty	..	..	18.3	8.2	1.54	120	32.0	3.2
Long pt., smooth	..	..	16.7	8.2	1.50	114	34.0	3.3
Long oval, warty	..	..	17.0	8.3	1.49	124	35.0	3.5
Long oval, smooth	..	..	16.1	8.2	1.44	117	35.0	3.4
Short oval, warty	..	..	14.7	8.5	1.46	118	35.0	3.6
Short oval, smooth	..	..	14.0	8.4	1.35	117	35.0	3.3

Table 21.
CORRELATIONS BETWEEN DIMENSIONS AND COLOUR.

				Mean Length.	Diameter.	Shell Thickness.	Wet Cacao Weight.	Number of Beans.	Single Bean Weight.
Very dark red	..	..	..	17.1	8.7	1.48	128	36.0	3.6
Green in furrows	..	..	..	16.9	8.3	1.50	119	34.5	3.5
Partially red on green	..	..	..	15.7	8.2	1.42	116	34.5	3.4
Splashes of red on green	..	..	..	16.2	8.3	1.46	122	34.0	3.7
Green	..	..	..	16.3	8.2	1.44	120	35.0	3.4
Green-white	..	..	..	15.2	8.0	1.35	120	36.0	3.4
White	..	..	..	16.0	8.2	1.42	118	37.0	3.4
Splashes of red on white	..	..	..	15.8	8.3	1.43	118	35.0	3.3
Partially red on white	..	..	..	15.6	8.3	1.41	117	34.5	3.4
White in furrows	..	..	..	16.9	8.5	1.53	125	35.0	3.6
Dark or crimson red	..	..	..	16.1	8.3	1.45	112	34.0	3.3

pod length and mean wet cacao weight compared with mean yield in pods per tree. There is an interesting correspondence between the three; length and wet cacao weight are always positively associated, but both are *positively* associated with yield in the case of the green base series and *negatively* in the case of the white base series.

Colour and bean characters.—A tendency for the partially red pods to have lower mean values is found with respect to bean number and weight and wet cacao weight as with respect to dimensions. The green-white types usually have numerous beans, but they are not heavy.

9.—General Summary.

A survey, both quantitative and qualitative, has been made of a representative sample of Trinidad cacao, which on account of its origin probably presents the widest variability of any cacao crop in the world.

The quantitative survey involved measurements or counts of pod length, pod diameter, shell thickness, number of beans per pod, weight of wet cacao per pod, and bean weight.

As a preliminary, the errors of measurement were statistically estimated, and the size of sample necessary from each tree in order to characterise it within defined limits of precision was determined. A standard sample of thirty pods from one tree gives means for pod length and pod diameter within five per cent. and means for shell thickness, bean number, and wet cacao weight within ten per cent. of the true mean, 95 times out of 100. The effect on quantitative characters of the position of the pod on the tree was measured, and it was found that samples exclusively composed of branch pods gave lower means than samples of trunk pods from the same tree. This fact

Type and pod value.—To summarise the most significant results, it appears that the largest pods are most often found in the long oval class, which contains also a fair proportion of heavy beans and high bean numbers. Non-pigmented and heavily pigmented pods are more frequently valuable than the intermediate colour classes, and warty types than smooth types, when gross weight of cacao is considered. As wartiness is a feature of the high quality species, Criollo and Alligator, and therefore presumably originally associated genetically with factors for quality, the latter is likely to be an important correlation. On the other hand the correlation is so imperfect that individual trees of high pod value may occur in any type.

once recognized, will not in practice introduce any appreciable error into the measurements, which in normal procedure are made on composite samples of pods from all parts of the tree.

The effects of increasing dryness of the weather during the crop season were measured, and it was concluded that samples taken during the month of maximum bearing will give mean values very close to those for the whole crop. Measurements in two years under quite different climatic conditions show that repetitions of measurements are not necessary within the limits of precision required for practical selection.

With these preliminaries settled, the survey was extended to a composite sample of about 950 trees scattered over the three main cacao growing districts of the island, and the results have been presented in tabular form, showing the limits and modes of variability for each of the characters studied.

Table 22.

		GREEN BASE.					WHITE BASE.					
		Very Dark Red.	Green in Furrows.	Partially Red on Green.	Splashes of Red on Green.	Green.	Green-White.	White.	Splashes of Red on White.	Partially Red on White.	White in Furrows.	Dark or Crimson Red.
Number of pods	..	47	38	35	41	41	47	34	34	41	37	41
Mean length	..	17.1	16.9	15.7	16.2	16.3	15.2	16.0	15.8	15.6	16.9	16.1
Mean wt. of beans	..	128	119	116	122	120	120	118	118	117	125	112

The qualitative survey involved a new classification of Trinitario cacao into 110 classes, based on shape and colour of the pods. All the trees used in the quantitative survey, and more than 1,000 others, were classified for type, 2,425 in all.

It was found that the mixing of genetic types is so thorough that a random composite sample of 1,000 trees is likely to present a close approxi-

mation to the distribution of type in the whole population.

Correlations were sought between type and quantitative characters, but although there were interesting indications of association in several cases, the broad result emerged that good yielding trees may occur in any shape or colour class, so that selection cannot safely be restricted to any limited number of types.

NOTE ON THE PROGENY OF A SINGLE CACAO TREE.

By F. J. POUND, B.Sc.

By the courtesy of the Director of Agriculture, Trinidad and Tobago, it has been possible to examine qualitatively and quantitatively a block of 80 trees at River Estate which are all the progeny of a single parent. The qualitative results are similar to those of Van Buuren (7), who described the progeny of a single Forastero tree in the Experiment Station at Peradeniya, and the quantitative results are of interest as an indication of what may be expected from seed selection in general.

The Parent.

The parent is tree No. 4927 River Estate, and was picked out in the early days of natural yield records on that estate as a consistently high bearer. This accounts for the progeny, which were planted to test their bearing capacity. It is a large and well-shaped tree, growing in a somewhat gravelly soil. Its pods are rather small, with a sharp and characteristic point, smooth, not very deeply furrowed, and very dark in colour. The pod characters of its nearest neighbours, which may possibly have contributed to the progeny by crossing, are compared with its own in Table 23. Its quantitative characters,

determined on a sample of 23 pods, are:—Length 13.8 cm., diameter 7.2 cm., shell thickness 1.3 cm., beans per pod 28, wet cacao per pod 66 gm. These are all low, and No. 4927 has not been considered by the Department of Agriculture to be suitable for the distribution of seed, in spite of its high bearing capacity.

Progeny—Distribution of Type.

Colour.—The colour distribution is as follows:—

<i>Green Base.</i>			<i>White Base.</i>		
Very dark red	..	32	Dark red ..	..	4
Green in furrows	..	17	White in furrows	..	9
Red-green	..	5	Red-white	..	12
Splashes on green	..	1	Splashes on white	..	0
Green	..	0	White	..	0
55			25		

The parent is "very dark red" so that nearly half of the progeny turn out as dark as the parent. A big proportion of the remainder are only slightly lighter in colour. It is interesting to find there are no pods with complete absence of pigment and only one with the first grade.

On the whole shape is not very variable. One quarter of the trees show the characteristic point of the parent. Among the remainder are types with a much longer point, others with no point and some with just a normal blunt point.

(7) Van Buuren, H. L. "An examination of the type-forms of fruit present in the progeny of a single Forastero cacao." *Trop. Agriculturist*, 71 (1928), 328-42.

Table 23.

POD CHARACTERS OF "4927" AND NEIGHBOURS.

	Colour.		Surface.		Size.
4927	Very dark red	.. ..	Smooth—medium furrows	.. ..	Medium pod.
1	Very dark red	.. ..	Warty—deep furrows	.. ..	Larger pod.
2	Green in furrows	.. ..	Smooth—medium furrows	.. ..	Medium pod.
3	Red white	.. ..	Smooth	.. ..	Smaller pod.
4	Dark red	.. ..	Smooth—medium furrows	.. ..	Larger pod.
5	Very dark red	.. ..	Smooth—medium furrows	.. ..	Medium pod.
6	Very dark red	.. ..	Smooth—medium furrows	.. ..	Medium pod.

Fifty-six progeny are smooth-skinned like the parent, 20 are rather rough, and four are decidedly warty. Sixty-three have medium furrows like the parent, nine have deep furrows, and eight are shallow.

Thus in colour and shape a good proportion of the progeny reproduce the characteristics of the parent. In colour, segregation occurs towards less pigment, and the trees with white-base pods may have arisen through crossing with the "red-white" neighbour.

The "warty" element has presumably come in from neighbour No. 1, and this may also account for some of the deep furrowed types since the warty types were deep furrowed.

Progeny—Distribution of Dimensions.

The quantitative variability of the progeny may be concisely expressed by a table of the extreme and modal values, as the frequency curves are as nearly normal as would be expected from the size of the sample (74 trees). This is done in Table 24.

The correspondence of the progeny mode with the parental mean is striking in every case, and forms the outstanding feature of this investigation. The parental values are all slightly below the

average for the Trinidad crop, and in the case of bean number a further enquiry was made into the question whether the low values in the parent and many of the offspring are due to low ovule number or to a high percentage of loss in development.

The mean number of ovules per flower and mean number of beans per pod in the whole crop are given for 13 trees in Table 25. The loss is fairly consistent from tree to tree, and on the average is very close to 25 per cent. It has been shown previously (8) that a loss of this order is not uncommon, and it may be concluded that the low bean number in No. 4927 and its progeny is mainly due to a low ovule number at the start, and not to abnormal subsequent loss.

Summary.

Variation in the progeny of a single tree has been found to be wide both in type and in quantitative characters. In the case of the latter, the most important conclusion is that the progeny mode is almost exactly the same as the parental mean for each character.

(8) Pound, F. J. First Ann. Rept. Cacao Research, 1931, p. 22.

Table 24.

COMPARISON OF PARENT AND PROGENY.

					PROGENY.			PARENT.
					Minimum.	Maximum.	Mode.	Mean.
Length	..	..	..	..	10.0 cms.	17.0 cms.	12.5 cms.	13.8 cms.
Diameter	..	..	..	..	5.6 cms.	8.3 cms.	7.1 cms.	7.2 cms.
Thickness	..	..	..	..	0.9 cms.	1.7 cms.	1.2 cms.	1.3 cms.
No. of Beans	..	..	..	..	15	40	27.5	28
Wet Cacao	..	..	..	..	25 gms.	125 gms.	65 gms.	66 gms.

Table 25.

OVULE AND BEAN NUMBER.

Mean No. Ovules.	Mean No. Beans.	Loss.
44.1	32	12.1
46.4	34	12.4
39.2	29	10.2
37.3	28	9.3
40.3	32	8.3
39.0	29	10.0
40.2	28	12.2
40.3	33	7.3
40.6	23	17.6
41.0	30	11.0
41.2	28	13.2
35.6	23	12.6
46.5	33	13.5
Mean	40.9	29.9
		11.1

CRITERIA AND METHODS OF SELECTION IN CACAO.

BY F. J. POUND, B.Sc.

The preliminary genetic survey of Trinidad cacao having been completed, the bulk of the work of the geneticist in the coming year will be devoted to practical selection of individual trees, some of which it is hoped will finally be established as clonal varieties. In its final details, crop improvement by selection must rank as a local problem in each cacao-growing country, but it is only by going through the whole process ourselves that we can meet the problems in general principles which are sure to arise, and which it is our particular business to attack. Consequently the time seems opportune for a detailed statement of the programme that we propose to follow, and indications of a general policy which on the grounds of work already done, we believe to be sound for the improvement of the cacao crop, not only in Trinidad, but elsewhere.

From the initiation of Cacao Research, it has been laid down that selection should be aimed primarily at increased yield, with enhanced quality as a secondary desideratum. Yield means yield per acre, rather than yield per tree, and measurements of the latter alone are of limited value until corrected to allow for the amount of land the tree occupies, which is usually a function of its age. In practice it is difficult to apply any accurate correction, and yield per tree is accordingly used as a basis for selection, but the age or size factor is not entirely overlooked. The yield of a tree under given conditions is, of course, the product of the number of pods which it produces and the yield value of the individual pod. The latter, as it has been shown, can be readily determined, and is expressed mainly in the average weight of wet cacao per pod, but the former can only be estimated when individual tree records of bearing are available for a period of several years. Hence it is impossible to make a final selection for high yield in one operation.

Two methods of procedure are logically possible. Either the first selection may be carried out on number of pods and a re-selection made on pod value, or the first selection may be based on pod value and the final selection on bearing. Actually both these methods are being followed, but the first only to a limited extent. The Trinidad Department of Agriculture has at River Estate some 6,000 trees, of which the individual performances have been recorded for many years, and these trees are now, at the invitation of the Department, being examined for pod value to permit a final selection of the best among them. In the absence of any other records of past yield, the second procedure is being followed for the greater part in our selection, and has everything to commend it.

It is easier, quicker, and consequently cheaper, to determine pod value than to record yield in numbers of pods. By this scheme the cheaper investigations are made on the bulk population

and the more expensive confined to a relatively small number of provisionally selected trees. Apart from that, the scheme reduces the error introduced by the age factor, which makes the fixing of limits a difficult task when selection is done on pod number, since a young tree may bear a large number of desirable pods for its size, and yet be overlooked or rejected when compared with its older neighbours. Finally, but by no means least, in selection on the basis of pod value first, an automatic selection for quality is involved without prejudice to yield. This point is highly important and needs a little elaboration.

From preliminary observations it appears that large pods do not necessarily, or even usually, have proportionately more beans than smaller ones, but that on the contrary their higher cacao content is chiefly made up by larger size of the individual bean. Consequently, if an amount of wet cacao equivalent to one pound of prepared beans is distributed in seven and a half pods instead of fifteen, not only is the labour of picking and breaking reduced to one-half, but the beans are much larger and rank as a much higher quality product. It follows that one tree giving fifty pods per annum may be more valuable than another giving a hundred, and if figures are drawn from the extremes of the crop, fifty of the largest pods are worth more than two hundred of the smallest.

In other countries a higher standard may be possible, or a lower one may be necessary, but under Trinidad conditions the limit for first selection may conveniently be placed at 7.5 pods to the pound of dry cacao, or 150 grams of wet cacao per pod. On good estates this criterion will pass about two per cent. of the tree population, a proportion leaving ample scope for subsequent elimination of mediocre bearers. It has already been shown (9) that high pod value and heavy bearing can and do occur together as characteristics of some trees, and there are no grounds for fear that in selecting large pods we shall eliminate all heavy bearers.

Our chief aim is thus to locate and tag, before the end of the 1933 crop season, one thousand trees passing the first test and worthy of further study. This means examination of not less than 50,000 trees, and a brief description will be given of the technique which renders such extensive operations possible.

Estate fields are visited by arrangement at times when a picking round is due and there is a good crop of ripe pods on the trees. Preliminary selection is done by eye, and all trees with obviously small pods are ignored. Many large pods have thick shells and few beans, but with

(9) "The Genetic Constitution of the Cacao Crop." Section 4.

practice it is possible to avoid most of those, as there are outward indications of thick shell, difficult to describe but easy to appreciate after detailed examination of some thousands of pods. In cases of doubt the pods are opened.

Trees with pods estimated by eye as promising are quantitatively examined by the methods of the genetic survey, but for speed in working a slight sacrifice of precision is allowable. The weight of the pod contents is rapidly taken on a spring balance specially made to our specification by Messrs. G. Salter & Co., Ltd., of West Bromwich and calibrated to show simultaneously the weight of wet cacao in grams, and the number of similar pods which will give a pound of dry cacao, assuming 60 per cent. loss in fermentation and drying. These balances are inexpensive, give sufficient precision for their purpose, and can be used by the planter in the field to estimate the relative values of different types of pod. The co-operation of planters is being sought and given in the search for the best trees in the Trinidad population. In cases where the number of pods available at a picking is less than the adequate sample of thirty, subsequent visits are made to the tree if its characters warrant. Trees selected in this way will be placed under observation for yielding power.

By the second selection on bearing capacity our thousand trees will be reduced in a few years to a number which we can handle more intensively.

Some idea of the type of expected yield may here be given.

On most estates in Trinidad during 1932 the cacao crop has followed that of the three plots in the Northern Range (10), and has in consequence given smaller yields than normal. In spite of this, some of the trees which were known to produce pods at the rate of $7\frac{1}{2}$ to the pound, gave yields of 60 pods, which meant 8 lb. of exceptionally high standard cacao. Few trees have been discovered of which the average pod rates less than 6 to the pound, and for these reasons the minimum yield of pods for any full bearing and healthy tree has been fixed provisionally at 50 per annum. This yield is probably at least four times as high as the present average, age for age. Ten to fifteen year old trees will be passed on an annual yield of 25 pods and in all cases due weight will be given to age, size of tree, and local environmental conditions.

However, in some parts it may prove undesirable to grow this "fine" cacao, and the local demand may reasonably be for a better yielding but inferior commodity. In order to ascertain definitely where the most efficient trees from the point of view of yield alone are to be found, a selection of a few types requiring more than $7\frac{1}{2}$ pods to the pound is being made, provided their yield in pods warrants it. The handicap on such trees, to allow for the extra cost of picking and

breaking, the often greater size of the tree and the smaller beans, has been fixed provisionally upon the following lines:—A few trees yielding pods at the rate of 10-12 to the pound were found bearing from 100-150 pods per annum at the age of 25 years. Taken in conjunction with the yield of 50 pods from trees classed as 7 to the pound it was decided that pending further investigation, a 10-pod to the pound tree yielding 10 lb. of cacao was as efficient as a 7-pod to the pound tree which gave 7 lb. of cacao and a 12-pod to the pound tree which yielded 12 lb. of cacao. For commercial use 12 pods to the pound was fixed as the extreme lower limit, since this is the average for Trinidad.

Even if in future years general cacao yields improve on those of 1932, we may assume from the work of the local Department of Agriculture that the trees selected will maintain their relative positions in the population. The difference merely implies that in an exceptionally good year higher standards of selection may be possible.

The heaviest bearing trees of all, in terms of pods, will probably be eliminated by this method of selection, for it cannot be denied that heavy bearing and small pods go together in the majority of cases. In relation to the amount of ground they occupy, the number of their pods which have to be picked and opened to make a pound of dry cacao, and the quality of their produce, the extremely heavy bearers are almost certainly not the most efficient yielders of cacao, but they may be of the greatest assistance in our studies of fruitfulness, and an independent selection will therefore be made of all trees reputed to bear 300 pods per annum or more.

Thus, in the course of a few years, selection should result in the isolation of trees falling into three classes. One class should contain the exceptionally heavy bearers, producing 300 pods per annum or more, retained for research purposes but expected to be of little commercial value on account of extreme smallness of pod. The second class should contain trees yielding at their best period probably between 50 and 100 pods per annum, the pods being $7\frac{1}{2}$ or less to the pound and the beans large. Ninety per cent. of their beans should weigh not less than 1.4 gms. each when dry, and large fractions should be separable with an average weight of 1.6 or even 1.8 gms. The third class should contain trees producing between 100 and 200 pods per annum, the pods being smaller and the beans rather flatter, with an average weight of 1.0 to 1.2 gms. Between the second and third classes the choice for commercial propagation will depend upon profitability when actual yield, cost of picking, and the magnitude of the premium payable for the larger beans are all taken into account, and it is likely that the choice will vary not only in different countries but in different localities of the same country, according to agricultural conditions on the one hand and the preferences of the market on the other.

(10) "The Genetic Constitution of the Cacao Crop." Section 5 and Figs. 7-9.

Beyond this point it would be premature to particularise, but it is already clear that subsequent work must embrace clonal multiplication, studies of compatibility, and preparation of commercial samples. The ultimate aim is a relatively small number of strains of all-round excellence, vegetatively multiplied, and of known behaviour under different conditions.

As many of the selected trees as can be handled with our present limited facilities will be propagated by vegetative means immediately, during 1933, into small clones of perhaps ten individuals of each, so that all subsequent propagation studies will be carried out on selected material, and by the time the selection is completed, data should be available concerning the behaviour of vegetative offspring.

Meanwhile, although the Cacao Research Scheme envisages the probability that vegetative propagation will ultimately be found desirable, it must inevitably be several years before sufficient data can become available for a decision to be made between seedlings and clonal material in plantation practice. We think it desirable to point out that a programme of selection such as we have outlined can begin immediately to contribute to the solution of the pressing problems of the industry. There can be no question but that all fresh plantings and all supplying of gaps in established plantations should be done with selected material. This has been repeatedly urged by the Trinidad Department of Agriculture, and is generally recognized in other cacao-growing countries, as shown by the inclusion of selection work in the programmes of the Departments of Agriculture concerned in each case. What has been less clear in the past has been the kind of selection which should be made, because until now there have been insufficient statistics available to give a clear and complete picture of the potentialities of the crop.

Seedlings from trees selected according to the principles outlined will have the general disadvantages of all cacao seedlings in variation from the parental type, but they will represent the best material that can be used pending further research into vegetative methods of propagation, and they will represent an appreciable advance on the present field populations.

There is one further point which may be touched upon in conclusion, albeit very lightly and tentatively. During the genetic survey and concomitant studies of yield variability in the field, it was found that "the bulk of the really good bearing trees are the older ones" (11). In conjunction with the observation that the majority of heavy bearers carry small pods, this suggests that there may be a correlation between age of tree and size of pod. Attempts will be made to test this possibility statistically, but it will not be easy to do so, since age must usually be a matter of somewhat doubtful estimate. It is desired at present simply to record that this possibility has not been overlooked. It carries no implication that the method of selection adopted is unsound, for even if the worst should be true and young trees selected on the basis outlined, should fail to maintain their high pod values in old age, they would still remain superior, age for age, to their unselected neighbours. The implications, if any, would concern rather the agricultural treatment of the crop and the length of life which trees should be allowed to attain. Furthermore, it is fair to add that such a correlation, if found, would not necessarily imply any direct or unavoidable effect of age on pod size, and in any case quite old trees have been found, the pods of which easily pass the selection standard.

(11) Pound, F. J. "The Fruitfulness of Cacao. Significance of the Relation between Total Variance and Mean Annual Yield." *Tropical Agriculture*, IX (1932), 288-290.

STUDIES OF FRUITFULNESS IN CACAO.

III.—Factors Affecting Fruit Setting.

By F. J. POUND.

Two aspects of yield in cacao are especially conspicuous and have been commented upon by most observers of the crop, the first that only a small proportion of the flowers remain on the tree for more than two or three days and exhibit appreciable increase in size of the ovary, the second that of the young fruits, or "cherelles", which do set, only a proportion, often very small, complete their development into mature fruits. Individual trees vary widely in their behaviour, and it is impossible at present to decide whether yield is more often limited by failure to set or by failure to mature after setting. That one or the other, according to circumstances, largely

determines final yield, can hardly be doubted, so that shy setting and heavy shrivelling are the two critical problems for solution in the analysis of factors contributing to bearing.

Both have received attention, and the evidence at present suggests that they have at least one aspect in common, namely, that both failure to set and loss of young fruit can be partly ascribed to a temporary shortage of nutritive substance at certain times. Thus neither can be a simple problem, for nutrition immediately implicates the foliar condition of the tree. In 1932, from data for trees at River Estate, a partial correlation was calculated between number of wilting cherelles and

degree of flush, allowing for variation in number of susceptible cherelles on the tree. This correlation was positive and would occur by chance about six times in a hundred trials ($r_{12.3}=0.3424$; $n=30$). The correlation between wilting and setting seven to eight weeks previously was also positive, and would occur by chance much less than once in a hundred trials, which confirms the finding of Rounce and Smart in 1928 (12) that cherelles are specially susceptible to wilt at that critical age. It appears significant that the critical age for wilting coincides with the time at which the cherelle is commencing its most rapid growth. Experiments are in progress designed to define the relation between nutrition and cherelle wilt, and further discussion is withheld for their completion.

The present paper deals mainly with the setting problem, which has logical precedence. In previous articles the mechanism of abscission of the flower was discussed (13), and evidence was adduced of partial self-sterility in certain trees (14). A fuller discussion now becomes possible.

Observations of Natural Setting.

In order to provide the necessary physiological background for the study of fruitfulness in its genetic aspects, the writer set out in January 1931 to collect data from field observations of the actual behaviour of cacao trees under estate conditions, with special reference to the inter-relations of change of leaf, flowering and setting.

A number of ten-year-old trees in a field at River Estate were examined weekly over nine months, ending in the middle of October. In May 1932 observations were resumed on the same trees and ten others of similar size, and continued until the end of the year. Other work prevented duplication of observations in the earlier part of 1932, but by starting in May the data were reinforced over the period when flowering was expected to be high and setting low. Small trees were used in order to facilitate the counting of young fruit on the uppermost branches. The results supplement the work of Pyke (15) on older trees, and the behaviour of the two sets is substantially the same, though there are interesting differences.

The figures collected have been translated into graphs. Fig. 22 shows the mean for all trees in 1931, and Fig. 23 the mean for all trees in 1932. Observations covered state of flush, flowering, setting and shrivelling of cherelles, but for simplicity in the present discussion the shrivelling curve is omitted.

Flushing.—In 1931 there were four periods during which a general flush occurred. The first flush, which commenced in January, was associated

with the maturing of the main crop and the onset of the dry season, and probably causally connected with those events. No reason for the second, which occurred at the beginning of April, is at once apparent, and the evidence is against rainfall as its sole cause. The third flush, in June, seemed to follow the advent of the rainy season. It was generally larger than either of the previous two, and after it was ended by the middle of July the trees put forth no fresh leaves until the end of August. The fourth flush occurred in September when the soil was already moist, and again without any immediately obvious cause. For the rest of the year it was quite usual to find individual trees in the field putting forth a few fresh leaves at irregular intervals, but there was no general flush again until the end of January 1932.

Although no detailed records of the experimental trees were made in 1932 before May, a flush was noted at the end of January, and Pyke's data for other trees on the same estate show such a pronounced flush in March that it seems safe to conclude that the experimental trees also put out fresh leaves in that month.

When observations were resumed at the beginning of May, flushing was strong but waning, and during June most trees were dormant in this respect. At the beginning of July another flush commenced which reached a peak during the second week in August and then matured rapidly, so that at the beginning of September the trees were again practically dormant. A smaller flush reached a peak in October, and there was a further slight change of leaf at the beginning of December.

Comparison of the two years shows at first more differences than resemblances, and these are undoubtedly results of the very different weather conditions, though the peaks of flush cannot all be simply related to the rainfall lines. There were six peaks of flush in 1932 (though the sixth was a small one) as compared with four in 1931, and the flushes of 1932 were in general at maxima on dates when in 1931 they were at or near minima. The point of closest correspondence is the flush which reached a peak at the end of September in 1931 and early in October 1932, and it is interesting to note that in both years there was a certain amount of irregular and individual flushing from this time to the end of December.

Relation of flowering to flushing.—The graphs provide general evidence of the kind which might be expected, namely that when a flush was taking place the intensity of flowering was considerably reduced, and that conversely flowering reached its peaks when vegetative growth was dormant. Such was notably the case in May and June 1931, August 1931 and June 1932. On the other hand there was a dip in the flowering curve at the end of May 1931 which cannot at present be satisfactorily explained, and there was in both years an interesting tendency for flushing and flowering to run parallel at about the end of September and subsequently.

(12) Rounce, N. V. and Smart, H. P. "The Shrivelling of Pods in *Theobroma Cacao*." MSS. Dissertation in I.C.T.A. Library.

(13) 1931 Report. Studies of Fruitfulness, I.

(14) 1931 Report. Studies of Fruitfulness, II.

(15) This Report. Physiology of Cacao, I.

Relation of setting to flowering.—It is very evident that setting bears little relation to the number of flowers on the tree. The setting curve is indeed the most consistent of the three, in showing one main peak in the latter half of each year, and in each case flowering was lower than in the earlier months, but whereas in 1931 flowering decreased steadily throughout the main setting period, in 1932 it showed a slight rise at the time of maximum setting. The correlation between flowering and the number of sets observed during the following week was worked out, and proved so small ($r = -.074$) that over the whole period it may fairly be stated that there is no correlation at all.

Relation of setting to flush.—An adverse effect of flush on setting, which is generally recognized and was expected to occur, was demonstrated most clearly towards the end of September, 1931, and in August, 1932. Yet on the other hand, immediately after the drop in the former case, setting rose again whilst the flush was still in full progress, and at the end of September, 1932, there was a still more marked tendency for the setting maximum to coincide with the simultaneous maxima of flush and flowering noted above.

General considerations of setting.—It is sufficiently evident from the sum of the observations recorded, that the inter-relations of rainfall, flush, flowering and setting in the cacao tree under Trinidad conditions are exceedingly complex, and that no one factor or simple set of factors can be held to govern setting.

Nevertheless, neglecting for the present argument the first four months of the year, for which records are not duplicated, it appears to be a safe conclusion that the setting in both years was essentially similar in its course. In 1931 there was an almost complete absence of setting during May and June, and in 1932 setting was low during those months, such setting as occurred being confined to a few individual trees, as discussed in a later section. In both years setting on any considerable scale virtually began in the middle of July, rose to a peak, and declined more gradually towards the end of the year. The main difference was that in 1931 a major flush had just finished when setting began, whilst in 1932 a major flush was just beginning. Consequently, in 1931 the setting curve rose without check to its peak early in September, but in 1932 it was checked almost as soon as it started, and the inhibitory effect of the major flush continued till the leaves matured, when the setting curve resumed its initiated rise and reached its peak at the end of September instead of the beginning. Differences subsequent to the main peak are minor, but of the same kind. In 1931 setting was temporarily checked by a flush just as it reached its maximum, but recovered even before that flush had passed its highest intensity, and continued on a lower and decreasing scale till the

end of the year. In 1932 the flush which coincided with the setting peak was less intense, and beyond a probable acceleration of its fall, it left the setting curve almost unaffected.

If this analysis is correct and generally valid for other years, it means that from the middle of July onwards some factors independent of those governing flush confer an increased *potentiality* for setting on the flowers of the cacao tree. This potentiality may be regarded as requiring other factors, probably nutritional, for its realisation. *Actual* setting will, on this hypothesis, tend to be inhibited by flush, because the young leaves compete with the flowers for the nutrients essential to the realisation of their potentiality.

As a working hypothesis this view of the facts helps materially in the study of the setting problem. It is evident from the graphs that the bulk of the crop follows as a result of setting from July onwards. It may be added in this connection that a much bigger proportion of the crop may result from setting after September than the graphs indicate, because cherelle wilt has to be taken into account in considering final crop, and it is not uncommon for a high percentage of cherelles previously set to shrivel during the September-October flush. It may not be economically profitable to increase the setting earlier in the year, yet a study of the causes preventing natural setting at that time may suggest methods of increasing the set from July onwards, and if simultaneously cherelle wilt can be decreased, particularly at the time of the September-October flush, appreciable increases in yield must result.

To sum up, then, the main result of these preliminary field observations is to focus attention on the fact that in May and June, when flowering is at its highest, little or no setting takes place whatever the state of the flush, whilst later (from about the middle of July onwards in the years under review), *potential* setting is high and *actual* setting seems to be largely controlled by the state of the flush.

The Effect of Manipulations on Setting.

The next step taken was to investigate the effect of manipulations, such as ringing, pruning and manuring of the trees, on setting. It was felt at this stage that nutrition, particularly the carbohydrate and nitrogen nutrition of the trees, was likely to explain partially, if not entirely, the different setting potentialities of the flowers at different periods of the year, and the experiments were planned with that hypothesis in mind.

Ringing.—Ten trees, similar in size to those already used for general observations, were ringed with a half-inch ring to the depth of the cambium on one branch only. In this way one-sixth approximately of each tree was ringed away from the remainder. The trees were visited and examined at the same time as the others. The amount of flowering was judged according to an arbitrary scale.

The rings were cut in April, 1931, about one month before the first observations were taken. Table 26 compares the mean degree of flowering on ringed and unringed branches for twelve consecutive visits from the end of May until the middle of August.

The total for the ringed portions is 11.20, giving a mean of 0.93, and for the unringed 7.37, giving a mean of 0.61. On the average the flowering on ringed branches was much denser than on unringed branches, and, unit for unit of length, there were about three times as many flowers on the ringed branches as on the unringed. (A mark of 0.61 is equivalent to three flowers per foot of branch, and 0.93 to nine flowers per foot of branch.)

The total setting was counted at irregular intervals and is shown in Table 27.

Since in each tree the ringed portion was only one-sixth of the total, the numbers of cherelles actually set on the ringed portions have been multiplied by five in order to make the figures comparable. On the ringed branches the number of sets (actually 264) thus becomes 1,320, which is about three times the number of cherelles set on the unringed portions of the tree, thus the *proportion* of flowers which set is roughly the same on ringed and unringed branches. Setting is not advanced in time by ringing as might be expected if carbohydrates were limiting. On other trees there was not much setting up to the end of July. By the end of August setting on ringed and unringed branches was taking place rapidly.

The experiment ended on 3rd October, 1931. Up to that period 105 of the actual 264 cherelles on the ringed branches had wilted, a fraction equal to 40 per cent. Of the 406 cherelles which set on the unringed portions of the trees, 230 had wilted, a fraction equal to 57 per cent. Although we do not know what happened subsequently, it seems evident that no more cherelles wilt, at least in the young stages, on ringed branches than on unringed branches.

The point brought out is that manipulations which tend to increase carbohydrate content of a branch do not increase the proportion of flowers which set, nor do they affect either the time at which setting occurs or the proportion of cherelles which wilt before they are about seven weeks old.

Pruning and manuring.—In the course of experiments primarily designed to shed light on shrivelling of cherelles, and carried out in the latter part of 1932, further facts emerged which have a bearing on the setting problem. Twenty-seven trees, scattered in a field and not adjacent, were selected as self-compatible and otherwise comparable, and divided into three sets of nine. One set was pruned heavily so that one-third to one-half of the leaf area was removed; a week later the second set was manured with nitrate of soda at the rate of 3 lbs. per tree; the third set was untreated, and served as control. At the commencement all shrivelled cherelles were removed and the remaining fruits (excluding those fully grown and nearly ripe) were counted, and at weekly intervals after treatment the wilted cherelles were counted. Four weeks later a second general census was taken. The results are shown in Table 28. The number of fruits set during the four weeks is obtained by adding the nett increase in fruits at the end of the experiment to the number which wilted during its course, and is shown in the fifth column. In passing it is worth noting that the wilting on manured trees, expressed as a percentage of the total fruit at the commencement, is less than half that on the controls, a result of such importance that a more comprehensive and critical experiment is planned for the current year to check it. So far as setting is concerned, the figures definitely support the working hypothesis that nitrogen nutrition plays an important part. They are necessarily preliminary, and similar experiments will need to be repeated in the earlier months of the year, and on a much more comprehensive scale from this point of view also.

Table 26.
COMPARISON OF FLOWERING ON RINGED AND UNRINGED BRANCHES.

Ringed	..	1.10	0.75	0.83	1.23	1.50	1.45	1.08	0.50	0.53	0.65	0.75	0.83	11.20
Unringed	..	0.68	0.53	0.75	0.86	1.03	1.10	0.78	0.25	0.20	0.28	0.48	0.43	7.37

Table 27.
TOTAL NUMBER OF CHERELLES SET.

Period.				Up to 31.7.31.	31.7.31. to 8.8.31.	8.8.31. to 22.8.31.	22.8.31. to 26.9.31.	26.9.31. to 3.10.31.	Total.
Ringed	..	..	..	85	25	200	890	110	1,320
Unringed	..	..	..	28	20	38	250	64	406

Before this part of the discussion is left for the present, it remains only to comment on the immediate effects of pruning on setting. Pruning was included in the experiment as an alternative method of temporary reduction of the carbohydrate/nitrogen ratio in the tree, and it is interesting to note that its effect on wilting of cherelles was similar to that of reducing the ratio by addition of nitrate. Its effect on setting, however, seems to have been the opposite, and this may most reasonably be taken to indicate that in setting the actual level of the carbohydrate or nitrogen supply is more important than the carbohydrate/nitrogen ratio, or at least was so under the other conditions of this experiment. This is not meant to suggest that pruning as a practice is to be discouraged. The subsequent effect of pruning at the proper time of the year cannot fail to be in the direction of increased yield following the production of a new and vigorous canopy.

The Genetical Aspect of Setting, and Insect Relations.

In Trinidad a "dry season" wetter than normal is generally supposed to favour an early cacao crop, and if this is true, there must under such conditions be more than the average setting in May and June. The year 1932 was such a season, and the graphs presented in the first part of this paper do show a slight rise in setting in May on the trees under observation at River Estate, which was not maintained in June. On older trees in both the Northern and Central Ranges it was noticed that there was good setting on some trees early in June, but this was definitely confined to certain trees, and others flowering equally well were setting no fruit at all.

This observation, viewed in the light of the partial self-incompatibility of certain clones at River Estate (16), suggested that those trees which were not setting might be likewise self-incompatible, and further raised the question whether they were at the time cross-compatible or not. Fortunately, experiments were already in progress which ultimately supplied a partial answer.

Five trees at St. Augustine were used for the first tests of compatibility by hand-pollination. They were all sibs from the same pod, occurring in

(16) 1931 Report. Studies of Fruitfulness, II.

one row, and numbered 4, 5, 6, 7 and 8 in the row. At the time they were all flowering equally, and the state of flush was low on each, so that as far as possible they were comparable in all respects. Between 19th April and 2nd May 1932, they were selfed with the following results:—

Tree.	4	5	6	7	8
No. of pollinations ..	30	30	28	23	30
No. set after six days ..	0	0	0	0	30

Obviously tree 8 alone was self-compatible, and tree 8 alone of the five was also setting naturally. A careful examination revealed the further fact that tree 8 alone was heavily infested with ants and aphides. The association of natural setting with ants and aphides has been pointed out by Harland (17) and Stahel (18), and in 1931 over a large field of trees the present writer found that all the trees which were setting fruit naturally were infested with sucking insects, and *vice versa*. That these insects accomplish a certain amount of pollination was shown by the writers mentioned, and again by the fact that buds on tree 8, when bagged, did not set when they opened unless insects were left inside or the stigmas hand-pollinated. The present results, however, indicate that pollination is only part of the story, and that in some way or other the sucking insects single out the self-compatible trees, or else they are themselves a cause of self-compatibility.

It has been postulated (19) that the abscission mechanism of the cacao flower works by turgor, and that setting results from a removal of osmotically active substances from the abscission region following the stimulus of pollination. It is quite possible that if ten or twenty aphides suck

(17) Harland, S. C. "Studies in Cacao, Part I. The Method of Pollination." *Ann. Appl. Biol.* 12 (1925), 403-409.

(18) Stahel, G. "Beitrage zur Kenntniss der Blütenbiologie von Kakao." *Verh. Koninkl. Akad. Wetensch., Amsterdam Afdeeling Natuurkunde*, 25 (1928).

(19) 1931 Report. Studies of Fruitfulness, I.

Table 28.

EFFECT OF MANURING.

Treatment.	Total Fruit at Start.	Total Wilt in 4 Weeks.	Non-Wilttable Cherelles after 4th Week.	Wilttable Cherelles after 4th Week.	Total Set in 4 Weeks.
Pruned trees	982	308	320	344	10
Control trees	747	455	200	455	253
Manured trees	819	284	225	797	487

sap from the pedicel they may reduce turgor sufficiently to retard the abscission mechanism, and so materially aid setting. On the other hand, the distribution of the insects suggests that for some reason the pedicels of trees 4 to 7 were distasteful to them. Possibly even both factors may combine to produce the association of aphides with self-compatible trees.

During May, pollen from tree 8 was used on flowers of trees 4 to 7 with the following results:—

Tree.	4	5	6	7
Percentage set	65	100	70	70

At the same time pollen from 4 on 8 gave 100 per cent. set, 5 on 8 gave 50 per cent., and 6 on 8 gave 100 per cent. Inter-crosses of trees 4, 5, 6 and 7 with each other were all failures except 6 on 4, which gave one set from ten pollinations.

Thus all the self-incompatible neighbouring trees were compatible with pollen of tree 8, and as there were hundreds of flowers produced daily on each, their complete failure to set naturally argues a complete absence during May of any agent of cross-pollination. It also indicates that when an early crop is set it comes entirely from the self-compatible trees in the population.

During June and July hand-pollinations were continued on the same trees in all possible combinations. Only ten pollinations were made at each time, but as every trial was triplicated, the striking differences must be significant (Table 29). As before, all trees are reciprocally compatible with tree 8, and although a slight setting occurred in other combinations, the maximum in such cases was always far below the minimum setting from compatible matings. During this period the flowering decreased on all trees and a change of leaf occurred. Aphides appeared on trees 4, 6 and 7 but still no natural setting took place. It was noticed, however, that when sets occurred from hand-pollinations between trees 4, 5, 6 and 7, it usually happened that the particular flowers which set had sucking aphides on their pedicels. Thus it still appeared that the presence of these insects aided setting, though their influence was not sufficient to overcome the genetic incompatibility. Agents of cross-pollination still seemed to be absent, or very inefficient.

During August it was noticed at Caura that some trees not heavily infested with aphides were setting fruit. At the same time there appeared thrips in the flowers and midges (*Cecidomyidæ*) were sitting about on spiders' webs. Tree 42, Caura, was flowering at a rate of 200-300 blossoms daily, but during the first two weeks in August it set naturally only about 12 in each week, which was less than one per cent. Twenty hand-selfings during the first week of August resulted in seventeen sets. Thus in this particular case, although the tree was compatible and setting naturally, pollination was at fault and many more cherelles might have been set had it been more

efficient. On seven non-setting trees at Caura during the second week of August, varying numbers of hand-selfings were made, and in no case was a set registered. Some of these trees might presumably have set on crossing with a self-compatible tree, but no crosses were actually made.

Table 29.

TRIPPLICATED POLLINATIONS ON TREES 4-8.

♂	♀	% A.	% B.	% C.	% Mean.
4	4	0	10	0	3.3
5	4	0	0	0	0
6	4	10	0	10	6.7
7	4	0	0	20	6.7
8	4	100	50	60	70.0
4	5	0	20	—	10.0
5	5	0	0	—	0
6	5	0	0	0	0
7	5	0	0	—	0
8	5	100	60	—	80.0
4	6	0	0	0	0
5	6	0	0	—	0
6	6	0	0	0	0
7	6	0	0	0	0
8	6	100	60	80	80.0
4	7	0	10	10	6.7
5	7	0	0	0	0
6	7	0	30	10	13.3
7	7	0	0	0	0
8	7	60	0	50	55.0
4	8	90	40	90	73.3
5	8	100	100	—	100.0
6	8	80	100	90	90.0
7	8	100	50	90	80.0
8	8	90	70	80	80.0

To summarize results to the end of August, it was evident that two classes of trees could be recognized in the field, viz.: those which were setting and self-compatible, and those which were not setting and self-incompatible.

In September, several more trees at St. Augustine commenced to set fruit. Twenty-seven sibs of tree 8 were tested for self-compatibility during each week in the month, with results set out in Table 30. These trees could be divided into three classes, viz.: thirteen self-compatible and setting naturally, eleven self-incompatible and not setting naturally, three self-incompatible but setting naturally. Some of the self-incompatible non-setting trees were infested with aphides. In other characters such as flowering and flush there

Table 30.
GENERAL SELFINGS AT ST. AUGUSTINE.

Tree.	Date of Pollination.					State.
	7th Sept.	14th Sept.	21st Sept.	28th Sept.		
2	o	o	o	o		Self-incompatible.*
3	No	pollinations;				tree obviously self-compatible.*
4	o	10	o	o		Self-incompatible.*
5	o	o	o	o		Self-incompatible.
6	o	o	—	o		Self-incompatible.
7	o	o	o	o		Self-incompatible.
8	50	90	—	—		Self-compatible.*
9	65	60	—	90		Self-compatible.*
10	o	o	—	—		Self-incompatible.*
11	o	10	10	10		Slightly self-compatible.*
12	o	o	o	o		Self-incompatible.
14	1	o	—	—		Self-incompatible.
17	—	o	—	o		Self-incompatible.
18	o	20	—	—		Self-compatible in December.*
19	71	80	80	100		Self-compatible.*
20	70	60	100	80		Self-compatible.*
23	No	pollinations;				tree obviously self-compatible.*
24	90	—	75	60		Self-compatible.*
25	—	100	—	—		Obviously self-compatible.*
26	75	—	—	63		Self-compatible.*
27	o	30?	o	o		Self-incompatible.
28	10	o	o	o		Self-incompatible.
30	Obviously self compatible	100				Self-compatible.*
32	40	40	30	10		Self-compatible.*
33	o	o	o	o		Self-incompatible.
34	o	o	o	o		Self-incompatible.
36	10	o	o	o		Self-incompatible.

was no significant difference between self-compatible and self-incompatible trees. The selfing test was repeated on 12th October and during November, and none of the trees registered any significant change in its position.

On 6th October crosses were made between self-incompatible trees and their nearest self-compatible neighbours, as follows:—

Female.	Male.	No. pollinations.	No. set seven days.
2	3	10	7
34	3	10	9
36	3	10	9
4	32	10	3
33	32	10	1
6	32	10	1
7	30	5	5
28	9	10	10
27	9	10	9
12	24	10	9
17	20	10	9
		105	72

* denotes setting a few cherelles naturally.

On 18th October a second series of crosses was made as follows:—

Female.	Male.	No. pollinations.	No. set.
2	3	10	9
36	3	9	7
34	3	10	9
4	32	10	5
33	32	10	7
5	32	10	4
6	32	10	1
7	30	10	9
28	9	10	6
27	9	10	9
12	24	10	8
17	20	10	8
11	9	10	4
		129	86

Tree 33 is the only tree giving inconsistent results. Tree 6 on both occasions gave poor set with pollen of 32, though it is perfectly compatible with 8, as shown earlier. Excluding these two trees the total set on the first occasion was 82 per cent., and on the second occasion 71 per cent. None of these trees at either time was setting naturally, and again the evidence points to an absence of cross-pollinating agents.

Inter-crossing of certain self-incompatible trees gave results as follows:—

Female.	Male.	No. pollinations.	No. set.
2	34	10	0
36	34	10	1
34	2	10	0
33	2	7	1
4	2	10	1
5	6	10	1
		57	4

The sets are definitely far below those from pollen of a self-compatible neighbour.

At the beginning of December two trees at River Estate were made the subjects of a special test. Both were typical "male" trees which had been flowering freely for several months, one of them at a rate of at least a thousand flowers a day, and set no fruit at all. The two showed different behaviour. The first, when pollinated by several distant self-compatible trees, set 16 fruits from 67 flowers, but its pollen was incompatible with the stigmas of all self-compatible trees on which it was tried. The second set nothing with pollen from distant self-compatible trees, but its own pollen in the reciprocal crosses gave good setting.

General Discussion.

From the evidence collected along several different lines of enquiry, it is evident that the setting curve of the Trinidad cacao crop is to be regarded as the resultant of three sets of factors, partly distinct from each other, but also in part inter-connected.

First there are such physical factors of the environment, as the presence or absence of pollinating agents. The reported observations emphasise the imperfection of our present knowledge of cacao pollination. It may be significant that general setting in 1932 was associated with the time when the flowers became thrips-infested, though it is difficult to see how these insects aid pollination. An interaction between insect relations and genetic factors lies in the fact that whilst for self-compatible trees it is only necessary to find agents of self-pollination, among which aphides can almost certainly be counted, for self-incompatible trees, which are by no means always barren, some agent of cross-pollination must be postulated, and the identification of such agent has hitherto baffled all investigators. The observations also emphasise once more that the whole pollination mechanism of cacao is inefficient under the conditions of cultivation, and although they leave undecided the question whether lack of pollination by itself ever limits yield, they suggest quite strongly that it may do so, especially in the case of self-incompatible trees.

Next for consideration are genetic factors which decide the compatibility of the stigmas on any tree with the pollen of the same tree or of its neighbours. The subject of compatibility in cacao is new, and much remains to be done in collecting facts before theories can be formulated. Nevertheless, the data already collected are sufficient to prove that degrees of compatibility play a large part in determining set, and hence final yield.

A note seems called for on the discrepancy between the high percentage of sets obtained from hand pollinations in compatible combinations and the much lower percentage of natural setting observed in the field, even under good setting conditions. The physical fact of adequate pollination will undoubtedly play a part in determining the difference, but it is likely that the time of pollination is equally responsible. Hand pollinations in these investigations have always been made a few hours after the opening of the flower, because it has been found by experience that this procedure gives the best setting. In cases of incompatibility in other species it has been several times shown that relative speeds of pollen tube growth are involved, and in some cases that by pollinating in the bud, seed may be obtained from otherwise incompatible matings. A review of this subject has recently been given by Sansome and Philp (20) and full

references need not be quoted here, but it seems very likely that these findings of other workers are applicable to cacao. During the course of some thousands of pollinations the writer has only rarely seen a flower pollinated naturally on the day it opened. The apparent absence of pollinating agents, indicated by the behaviour of self-incompatible trees, may in reality be not a total absence, but absence in the morning hours when the flower is freshly opened. Harland (l.c.) describes the cross-pollinating agent of which he found evidence as "night flying", and the writer (21) has found that the anthers of cacao do not dehisce until 6.30 a.m.

Environmental conditions at certain seasons of the year may quite possibly bring about either an earlier dehiscence of the anthers or a delay in the initiation of abscission of the flower, and either would tend to increase natural setting. These possibilities introduce the question of interaction between genetic and physiological factors.

Superimposed, as it were, on the physical factor of pollination and the genetic factors governing compatibility, are the physiological factors which finally determine whether a flower, genetically self-compatible and adequately pollinated, shall set or absciss. These physiological factors are determined ultimately by the environment, but more immediately by the physiological state of the tree, which integrates present environment with past history. Consequently it is not to be expected that their effects can be easily and directly explained in terms of rainfall. Nevertheless, it is believed that when the contributing factors have been sorted out further, it will ultimately become possible to explain the physiological aspects of setting in terms of the nutrition of the tree, and nutrition very largely in terms of water balance. The evidence at present points to the carbohydrate and nitrogen metabolism of the tree, especially the latter, as intimately concerned.

Summary.

A survey is presented of the course of fruit setting on certain trees during 1931 and 1932, and its relation to flowering and more particularly to flushes of new growth, is discussed.

Preliminary experiments in modifying the degree of setting by manipulations, such as ringing and manuring, are reported.

Further evidence is adduced for the wide occurrence of self-incompatibility among cacao trees, and it is pointed out that setting in May and June, when it occurs at all, seems to be confined to self-compatible trees.

The relation of insect fauna to setting is considered, and it is concluded that much more setting might take place on self-incompatible trees at certain times if there were more efficient agents of cross-pollination in the cacao field.

Setting is discussed as the resultant of pollination, compatibility and physiological factors, and the hypothesis advanced that other factors being favourable, it is intimately connected with the nitrogen metabolism of the tree.

(21) 1931 Report, p. 26.

(20) Sansome, F. W. and Philp, J. "Recent Advances in Plant Genetics. London, J. and A. Churchill, 1932."

THE PHYSIOLOGY OF CACAO.

I.—General Observations of Growth, Flowering and Fruiting.

By E. E. PYKE, B.Sc.

From the beginning of the year 1931, weekly observations have been made on two plots of plantation cacao with reference to the vegetative and reproductive condition of the trees. The ultimate object is the interpretation of yield fluctuations in terms of plant physiology, and in particular the determination of the physiological causes of cherelle withering. Immediately, the need is for records of what cacao trees actually do in the course of a season. The localisation in time of their growth-flushes, flowering and fruiting, is much less clearly marked than in trees of temperate regions. Largely, no doubt, this is because of the absence of extreme temperature fluctuations, and in all probability the mixed genetic constitution of the crop helps to obscure its periodicity. Whatever the cause, the result is that existing knowledge of cacao tree behaviour is vague, and the simple presentation of facts for certain trees over a certain period of time should have its usefulness.

The Plots.—Of the plots selected for observation, one, of 50 trees, is situated at River Estate, Diego Martin, and the other, of a 100 trees, in the Caura valley. Both are upon flat ground, and under good cultivation. The trees on the River Estate plot are spaced 18 feet by 18 feet and are of even age, about 20 years old. The spacing at Caura is about 12 feet by 15 feet and age is rather variable, some very old trees being included in the plot, and also a considerable number of young trees and supplies. Both plots are well drained; the River Estate plot has a gully running through it, and the Caura plot has a small river upon one side. Shading upon both plots is by Immortelle trees; the River Estate plot is rather more shaded than the Caura plot. The respective elevations are about 50 feet at Diego Martin and 400 feet at Caura. The fortnightly rainfall figures for the period of the observations are recorded on the curves of tree behaviour (Fig. 24).

Observations and Methods.—The aim has been to obtain as wide a range of information as possible from each tree, whilst maintaining a fair standard of accuracy, so that if necessary, comparisons can be made between different trees or groups of trees. Actual measurements of growth increments or accurate counts of flowers are impracticable on the number of trees chosen, and in the initial stages of research it has been judged better to retain a fairly large sample of trees than to adopt a high standard of precision on a few trees. Consequently, recourse has been had to a system of marking, which, whilst somewhat rough and purely arbitrary, is capable of quantitative treatment when the observer has had sufficient practice. After observations had been made by this method for some months,

and experience gained of it, it was thought advisable to discard entirely the figures collected at the outset and to use only those obtained after the technique could be accepted as stabilised. For this reason the records now presented start in June, 1931, and stop at the beginning of January, 1933.

The observations taken, tree by tree, on the two estates, with the technique appropriate to each, are as follows:—

(i) *Flowering.*—The general state of flowering for the whole tree (neglecting young suckers) is judged, and a mark given according to the distribution and density of open flowers. The marks are:—

0.—No blossom, or a very few.

$\frac{1}{2}$.—*Sparse* but generally distributed flowers on top branches only, or on lower branches and trunk only.

1.—*Fair* and generally distributed all over the tree, that is, usually, 25-50 per cent. of cushions with a few open flowers, or dense but localised to top branches or lower branches and trunk.

$1\frac{1}{2}$.—Fairly dense all over tree, that is, most of cushions with several open flowers.

2.—Very dense over the whole tree. All cushions flowering with four or more open flowers.

With practice it is possible to judge a tree's flowering condition and to assign it a mark with a fair degree of certainty, and the method has the advantage that the whole tree is taken into account. If the flowering estimate is based upon a count taken on any one zone, such as the trunk or lower branches, many trees are likely to be inaccurately represented, as quite a considerable number of trees flower mainly on the topmost branches. Although this scale is very coarse the variations of flowering in the trees under observation have been so marked that no difficulty has been experienced in noting the changes.

(ii) *Flowers Set.*—This estimate is based upon a direct count when the tree is not setting heavily and upon an estimate from a direct count upon a sector of the tree, multiplying then by a factor, when the tree is setting heavily. The estimate by counting will probably always be somewhat less than the true number, as it is very difficult to avoid missing some set flowers, especially those on the upper branches. The difficulty arises as to the definition, for recording purposes, of a set flower, and its distinction from a very young cherelle. In order to get a check upon this, a number of flowers which were just visibly fertilised were tagged with wool and examined after one week. The amount of growth of the young fruit was found to be fairly constant for all the flowers, the length being about 5 to 6 mm.

In observing, all those young fruits *smaller* than 6 mm., *i.e.*, those in which the flower had probably been set since the last observation, were counted as set flowers, and those larger were counted as young cherelles.

(iii) *Young Cherelles*.—The upper length limit for a pod to be classed as a young cherelle was taken as 7 cms. This length corresponds roughly to the time at which the fertilised egg undergoes its first division, and it also is the length above which the pods no longer tends to wither, apart from fungal attack or extreme drought. The young cherelles were estimated by a direct count of all the pods in the length group 6 mm. to 7 cms. In a few very heavy bearing trees the estimate was obtained from a count on a sector only of the tree, *i.e.*, on the ramifications from one of the main jorquette limbs.

(iv) *Withered Cherelles*.—The estimate of these was always by a direct count. At first a system of marks was tried, but the direct counting method was substituted as being much more accurate. As each pod is counted it is knocked off the tree with a pole, so that the number at any one observation represents the number accumulated since the last reading.

(v) *Pods over 7 cms. long*.—The number of pods over 7 cms. long was recorded from time to time. This statistic was not recorded weekly, as on large, well-bearing trees the time required for the observation is rather long, and since withering of pods over 7 cms. is unusual, a sufficiently accurate estimate can always be obtained by working back from the recorded crop pickings.

(vi) *Canopy of Tree*.—From time to time the condition of the canopy of each tree was noted and entered. Five classes were distinguished:—Very poor, poor, fair, good, and very good.

(vii) *Dropping of Leaves*.—Short notes were made when a tree was noticed to be losing leaves. The condition is easily noticed, as isolated leaves turn yellow before dropping.

(viii) *Flushing*.—This is a general term used to describe the formation of new growth on the trees. The flushing was estimated by a scale of marks, based on the amount of young growth at the time on the tree, or the proportion of the possible number of terminal buds of shoots (either terminal or axillary) which were pushing. The marks were awarded upon number of flushes only, not upon the individual vigour, although notes were appended describing the general vigour of the new growth under a "remarks" column. The marks ranged from 0 to 10, according to the following scale:—

0.—No flushing—dormant.

1.—A few flushes.

2.—Some, but comparatively few, flushes distributed over tree (or localised).

3-4.—Considerable flushing distributed.

5-7.—"Partial flush", *i.e.*, often the regeneration of canopy after partial defoliation.

8-10.—"General flush", complete regeneration of canopy after, or at the time of, almost complete defoliation; practically all the buds push simultaneously, or over a period of one to two weeks.

It will be seen that the numerical scale is an arbitrary one, designed partly for convenience of notation, and is not necessarily directly proportional to the exact amount of new growth on the tree. However, it is deemed sufficiently proportional to allow of the marks being added up and compared week by week. When comparing the performance of different trees, it is noticeable that whereas one tree will completely regenerate its canopy by one "general flush" lasting perhaps two weeks in the actively growing stage, another tree will attain the same end by a series of "partial flushes" or less, extending over a few months.

General Results.—The records of flushing, blossoming, and setting of young fruits for the River Estate plot are presented graphically in Fig. 24.

During the period of observation, one of the River Estate trees and two of the Caura trees have died, but as they made little contribution to the records at any time, no amendments have been made. Withering of cherelles has been omitted from the graphs, partly for simplification, but largely because this quantity varies so widely from tree to tree that it can be better dealt with in a discussion of individuals.

Periodicity of Flush.

A.—GENERAL.

(1) The flush curve is of a regular form, and consists of a series of alternate peaks and dips.

(2) The amount of flushing is practically negligible for several weeks during the dips.

(3) Peaks occurred during June, September and December in 1931, and during March, May, August, October and December in 1932.

(4) The intervals of the first five flush periods are remarkably constant, at about 85 to 90 days but it remains for further data to show whether this constancy will be maintained, in view of the occurrence of two shorter flush periods of about 60 days towards the end of 1932.

(5) *Times of principal flushes*.

(i) The beginning of the rainy season was marked by a general flush, which was heavier in 1931 than in 1932, possibly due to the greater climatic change in 1931. The flush occurred also about one month later in 1931.

(ii) Another flush followed about 85 days later, in August-September, in both years.

(iii) There were one or more smaller flushes towards the end of the wet season, while the crop was maturing. (One in 1931; two in 1932.)

(iv) A vigorous flush occurred in the dry season of 1932, in February-March, as the crop was being picked, and there were also indications of a similar flush in 1931.

B.—PARTICULAR.

(1) No correlation was found between the number of flushes, or the total amount of flushing, of an individual tree, and its yield.

(2) During the period under record, eight flushes occurred. Sixty-four per cent. of the trees responded to all the flushes, twenty-eight per cent. to seven flushes, and only eight per cent. to less than seven.

Periodicity of Flowering.

A.—GENERAL.

The blossoming is represented by a fluctuating curve which shows a periodicity comparable to, but less marked than, that of the flush curve, superimposed upon a marked seasonal trend.

Principal blossoming periods.

(i) A dormant period during the first four months of the year, in which there is practically no blossoming.

(ii) A sharp rise during May-June, unaccompanied by much setting, the so-called "crazy flowers."

(iii) A further period of blossoming, with setting, in July-August, lasting until the end of the year.

Relation to flush.

Shorter period fluctuations.—In general there is a correspondence with flush movements, *e.g.*, of seven main peaks in the blossoming curve from June 1931 to December 1932, five corresponded to flush peaks. Two reached their maxima before a flush and were depressed by the flush, but recovered after the flush passed the maximum (August-September, 1931, November-December, 1931). There was no increase of blossoming corresponding to the flush of February-March, 1932.

B.—PARTICULAR.

The actual amount of blossom formed varies greatly from tree to tree, but there appears to be no correlation between the amount of blossom formed by a tree and its subsequent yield. The proportion of blossoms setting, and the proportion of set pods (cherelles) wilting are both factors highly variable from tree to tree, and their combined effect overwhelms any possible influence which the amount of blossom may have upon yield.

Periodicity of Setting.

A.—GENERAL.

(1) There is a marked yearly cycle. Setting, in both years, was *nil* until June, when it rose steeply to a first maximum in September, 1931, and in July, 1932.

(2) After the first main period of setting in August-September-October, 1931, there was a short period of low setting in November, followed by another rise, which fell off gradually until, in February, 1932, there was practically no setting.

(3) The trees were setting practically no fruit until the end of May, 1932, and during June and July the curve rose to a maximum at the end of July. As in 1931, a dip occurred in November, followed by a rise during December.

B.—PARTICULAR.

There appear to be two kinds of trees in respect of setting behaviour, intermittent and continuous setters. The dips in the curve for the total setting of the plot are frequently correlated with the complete cessation of setting at the time by most of the intermittent setters. Most of the intermittent setters showed this property in both the 1931 and 1932 seasons. On the other hand, the continuous setters set some fruit every week throughout the setting season. The highest yielding trees in the 1931 crop nearly all came from the ranks of the continuous setters, although several mediocre yielders were also continuous setters. Of the intermittent setters only two yielded over sixty pods each; the remainder had an average yield of only twenty-eight pods per tree.

Number of trees under observation at

River Estate 50

Number of supplies and sickly trees .. 12

Number of healthy bearing trees .. 38

Of 38 bearing trees:—

24 continuous setters, average yield, 80.4 pods per tree.

14 intermittent setters, average yield, 37.6 pods per tree.

The yield from the "continuous" trees is distributed approximately normally about the mean (Fig. 25), while that from the "intermittent" trees has an asymmetric distribution (Fig. 26). It is probable that the intermittent setting and comparatively poor yielding may be found to be associated with self-sterility, making the tree dependent for fruit setting upon cross pollinating agents, which may be abundant only at certain times.

C.—RELATION TO FLOWERING.

There is a general correspondence in the forms of the annual curves for setting and blossoming. The chief difference lies in the occurrence of a period of heavy blossoming at the beginning of the rainy season, which is not accompanied by any setting. This is the so-called "crazy blossoms" period, and occurred in June-July, 1931, and in May-June, 1932.

D.—RELATION TO FLUSH.

In both years a fairly heavy flush occurred during the period of maximum setting, and was correlated in each case with a sharp but temporary reduction of setting, which recovered as the flush passed its maximum.

Periodicity of Cherelle Wilting.

The tendency for a proportion of the young pods to wilt is a very constant feature of the cacao crop cycle. Individual trees vary greatly in their liability to cherelle wilting, so much so that a general graph for a plot as a whole is of limited use in considering this statistic. It is possible to note, however, that in general an increase of wilting occurs at the time of, or immediately following each flush. In some trees a very slight flush is followed by the loss of a large proportion

of the cherelles, whereas in others, few cherelles wilt even during heavy flushes. On the River Estate plot the ratio of pods wilted to pods set ranges from 92.5 per cent. to 19 per cent. with a mean of 69 per cent. There appears to be no very close connection between this percentage wilting and the final crop of the individual tree. Thus good bearers often produce their crop in spite of a high percentage wilting and not because of a low one, and similarly, poor bearers show no greater proportionate wilting, in general, than the good bearers.



FIG. 1. A—TYPICAL FAN CUTTING.

B—TYPICAL CHUPON CUTTING. NEW GROWTH ONLY SHOWN. OLD LEAVES
OMITTED FOR SIMPLIFICATION OF DIAGRAM.

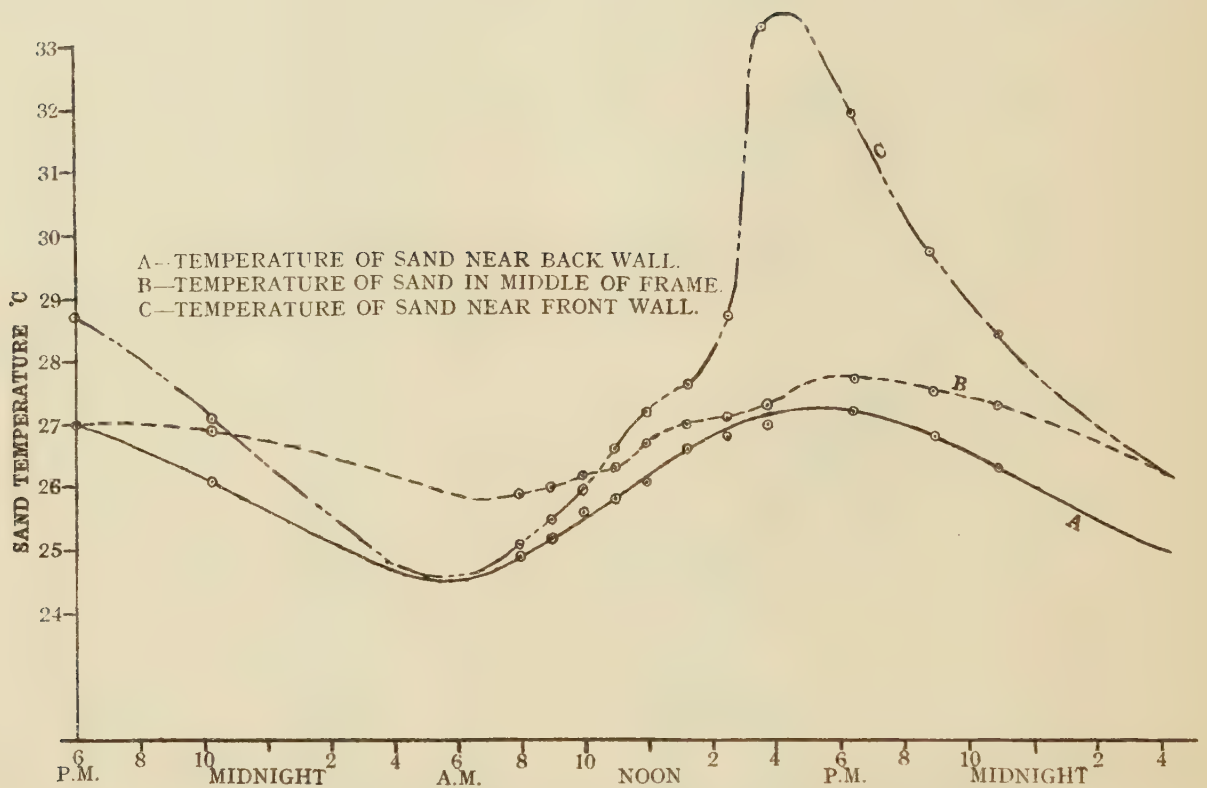


FIG. 2. DAILY TEMPERATURE VARIATION OF SAND IN COOL FRAME.
 DATE OF OBSERVATIONS, 22.11.32. MIDDLE CHAMBER, FACING WEST.

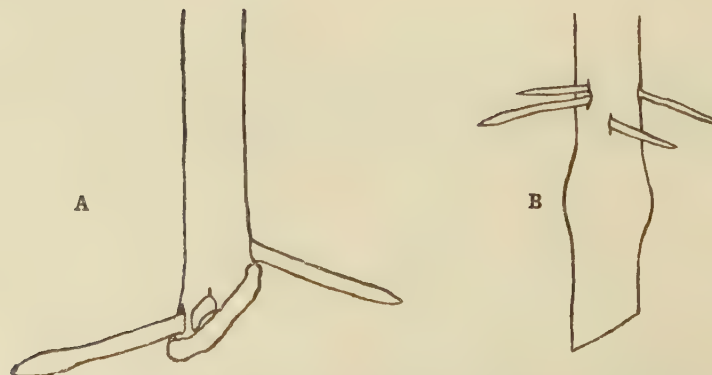


FIG. 3. TYPES OF ROOTING IN A--MOIST SAND AND B--WET SAND.

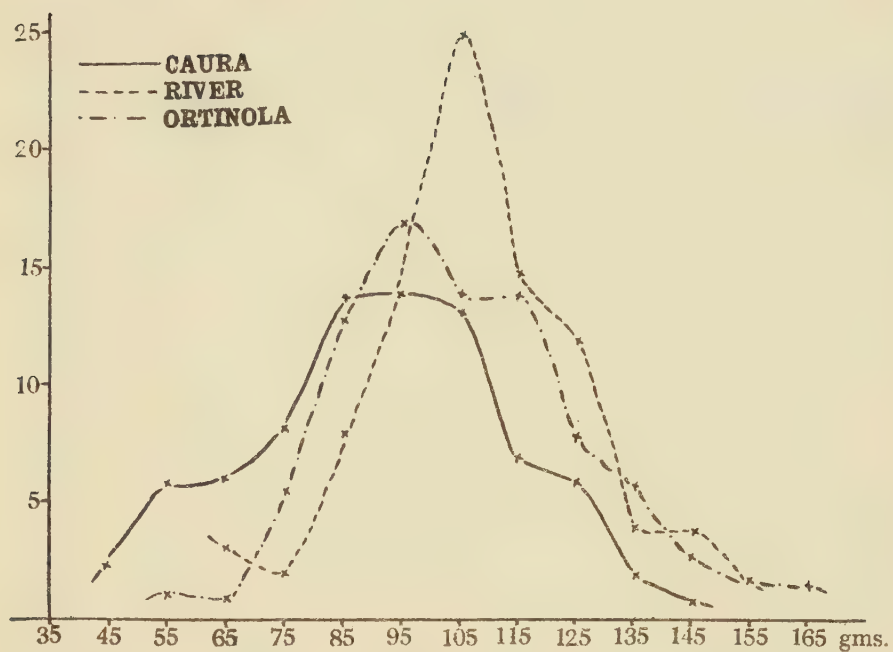


FIG. 4. FREQUENCY CURVE OF WET CACAO WEIGHT

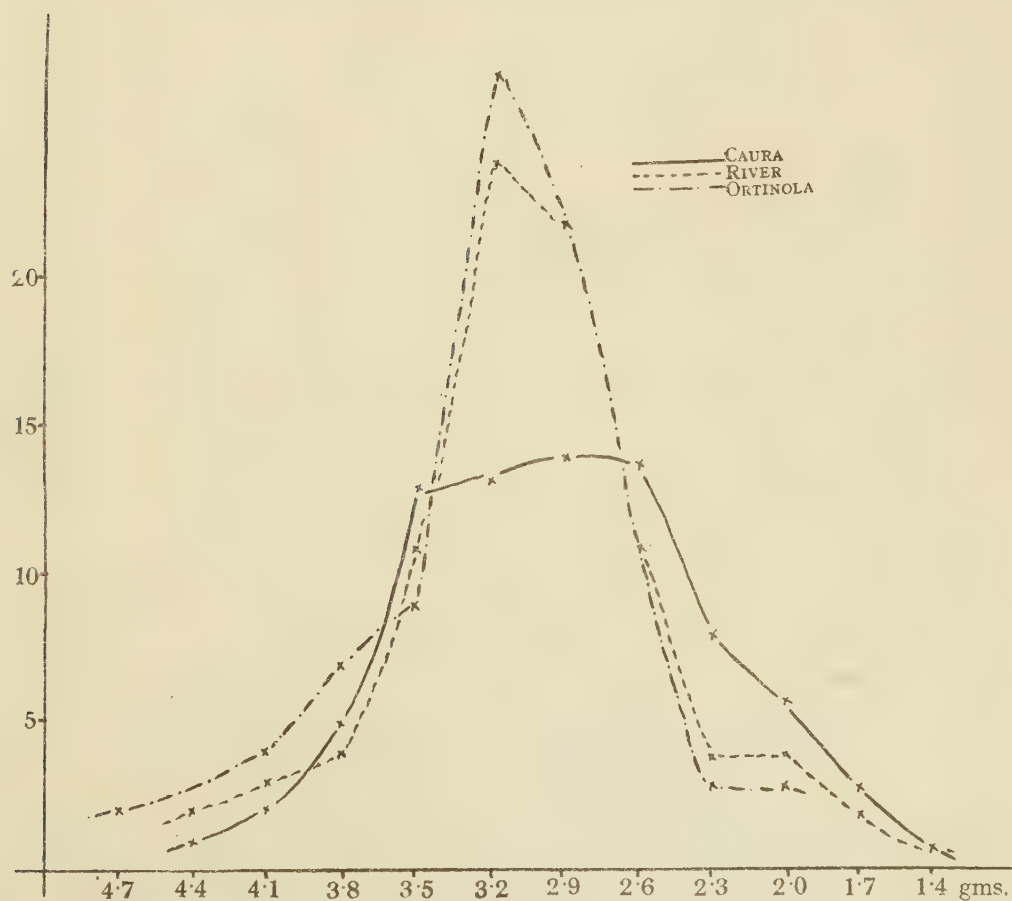


FIG. 5. FREQUENCY CURVE FOR MEAN WEIGHT OF A SINGLE BEAN.

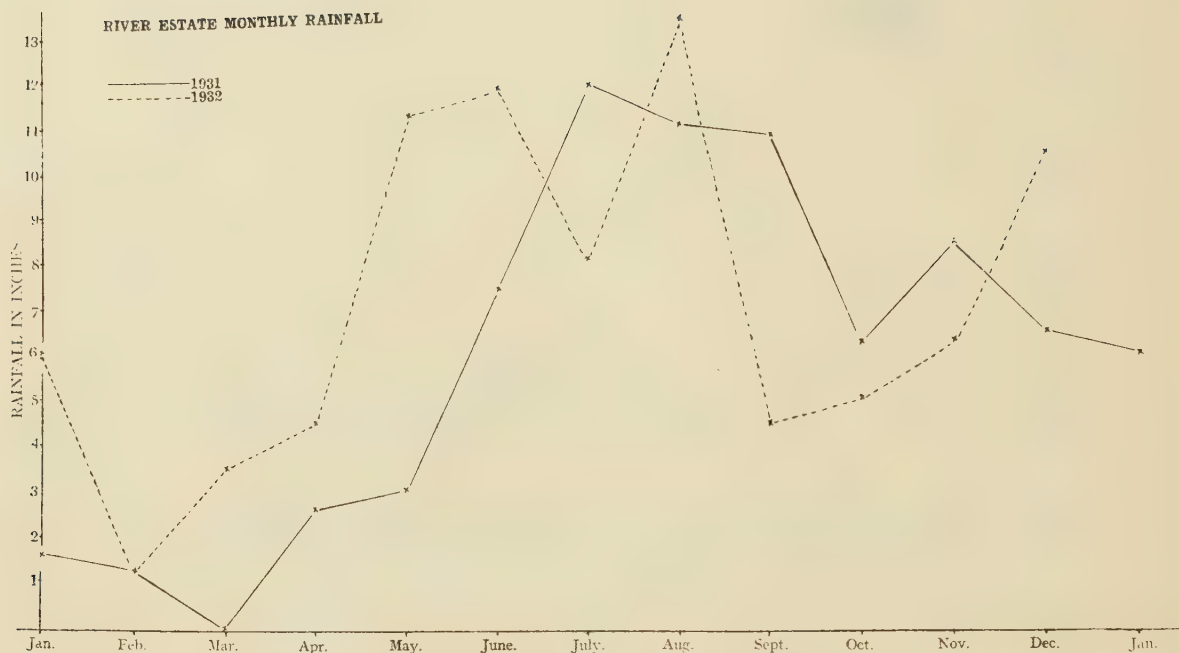


FIG. 6. MONTHLY RAINFALL, RIVER ESTATE, 1931 AND 1932.

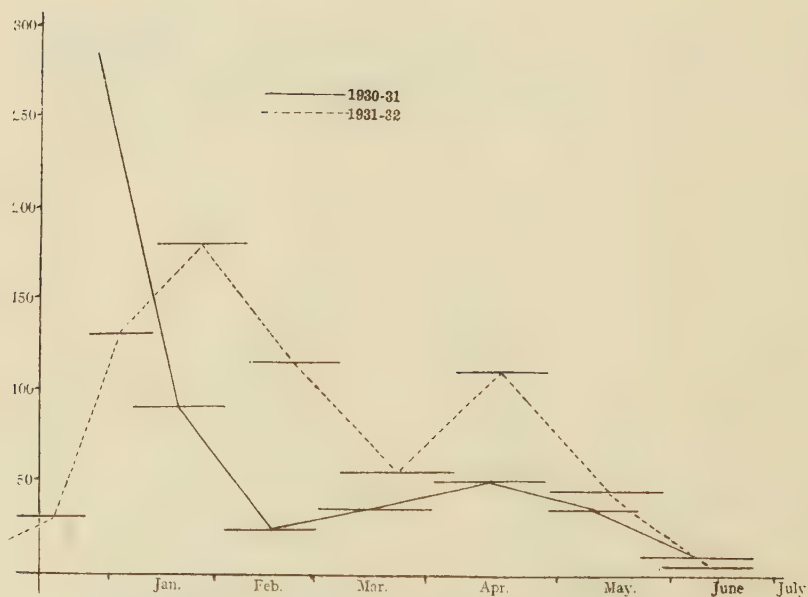


FIG. 7. COMPARISON OF PODS REAPED AT RIVER ESTATE, IN 1931 AND 1932.

(The horizontal lines represent the time period between two consecutive harvests. The altitude of each line represents the average weekly production of pods over that period. By joining the middle points of these lines an approximate graph of the intensity of crop is obtained.)

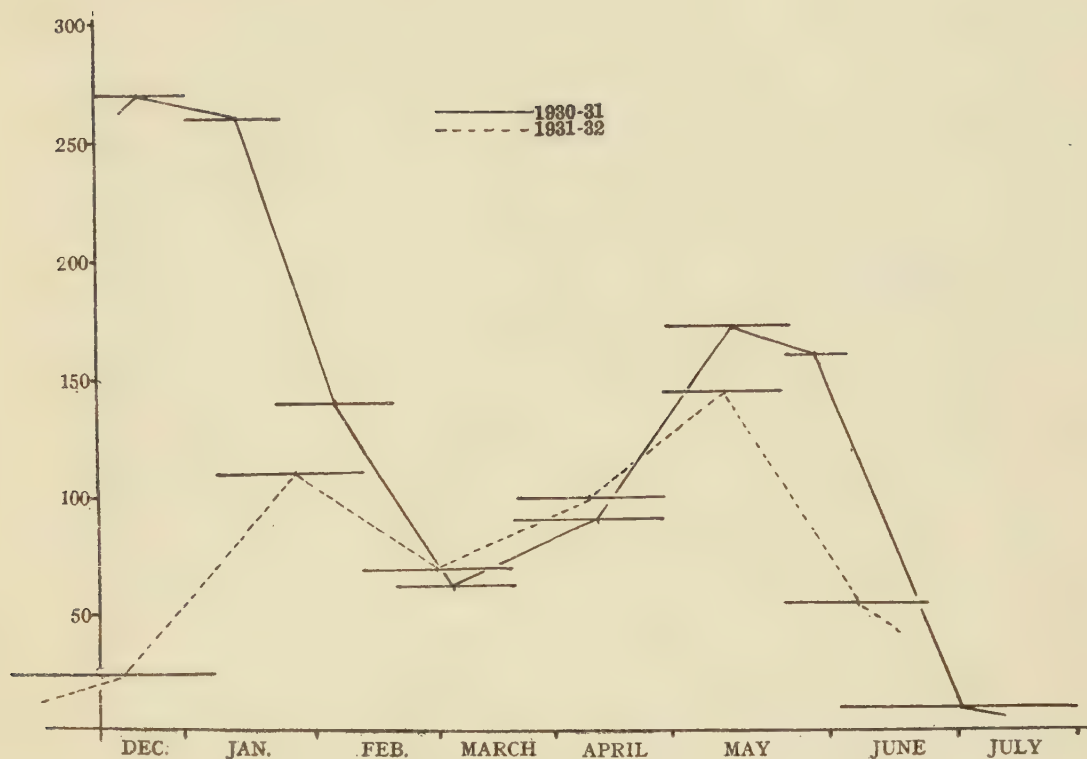


FIG. 8. COMPARISON OF PODS REAPED AT CAURA, 1931 AND 1932

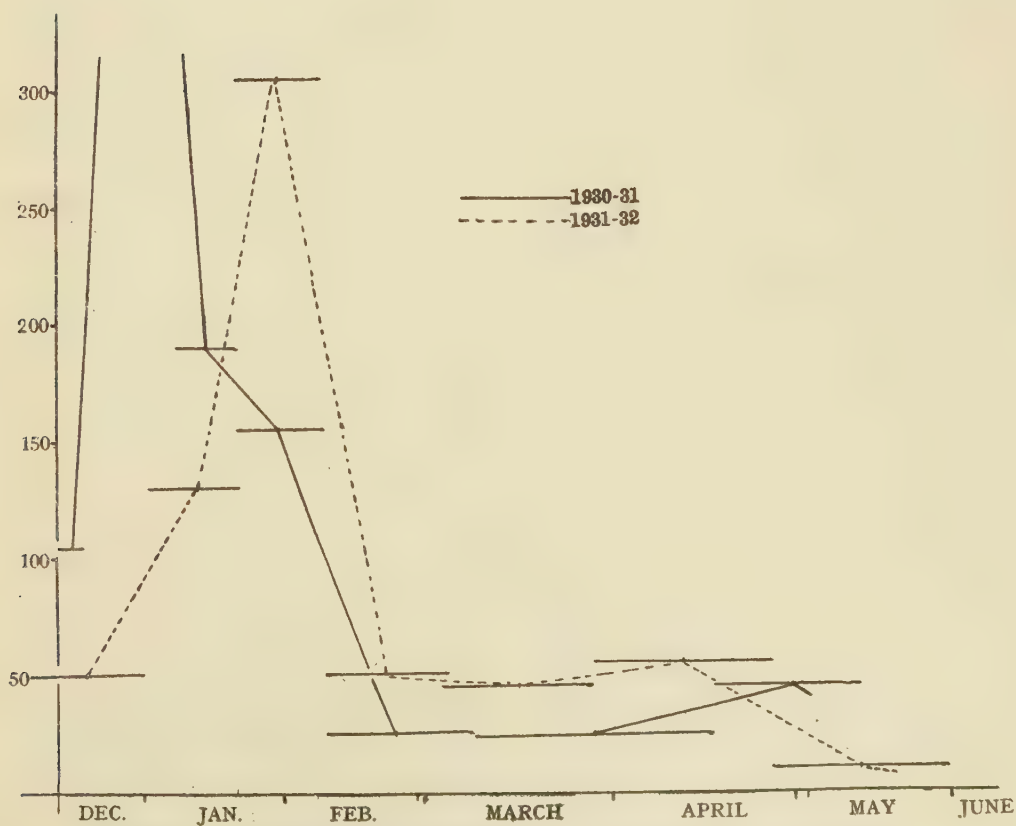


FIG. 9. COMPARISON OF PODS REAPED AT ORTINOLA, 1931 AND 1932.

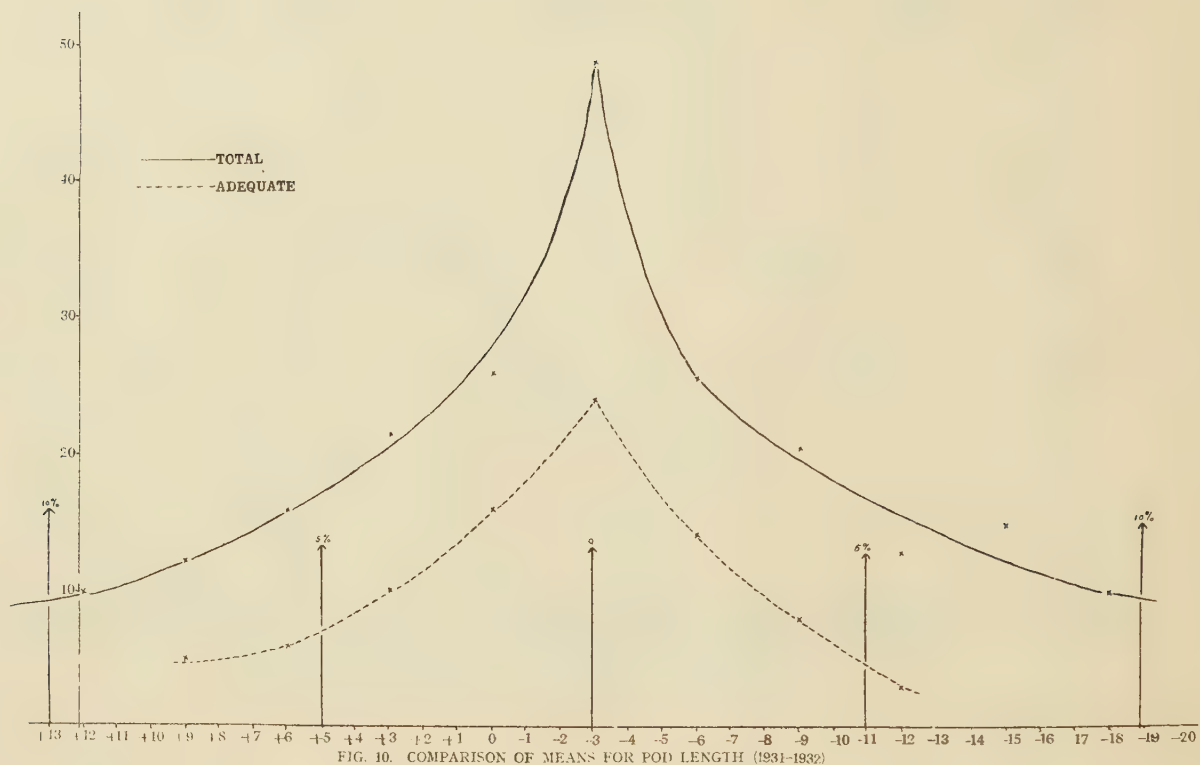


FIG. 10. COMPARISON OF MEANS FOR POD LENGTH (1931-1932)

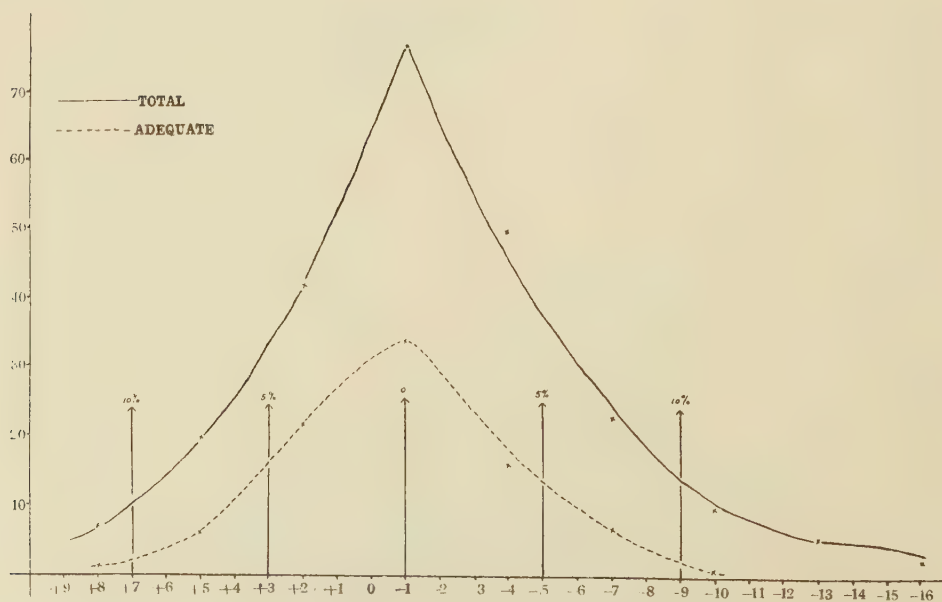
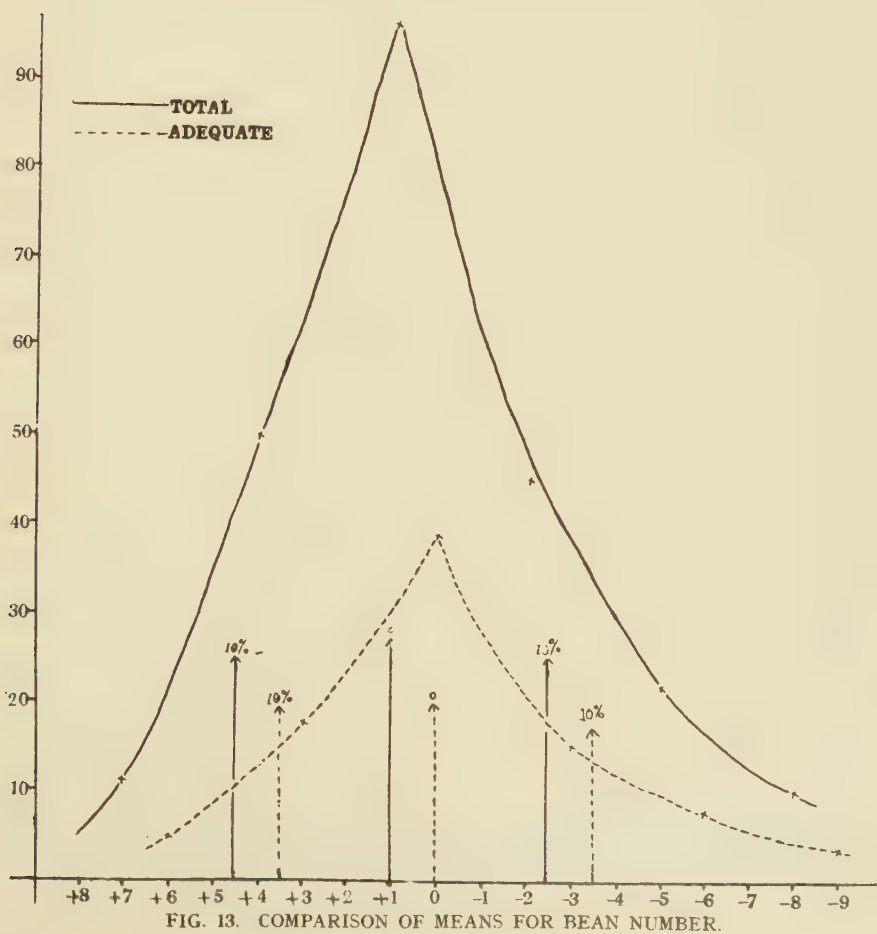
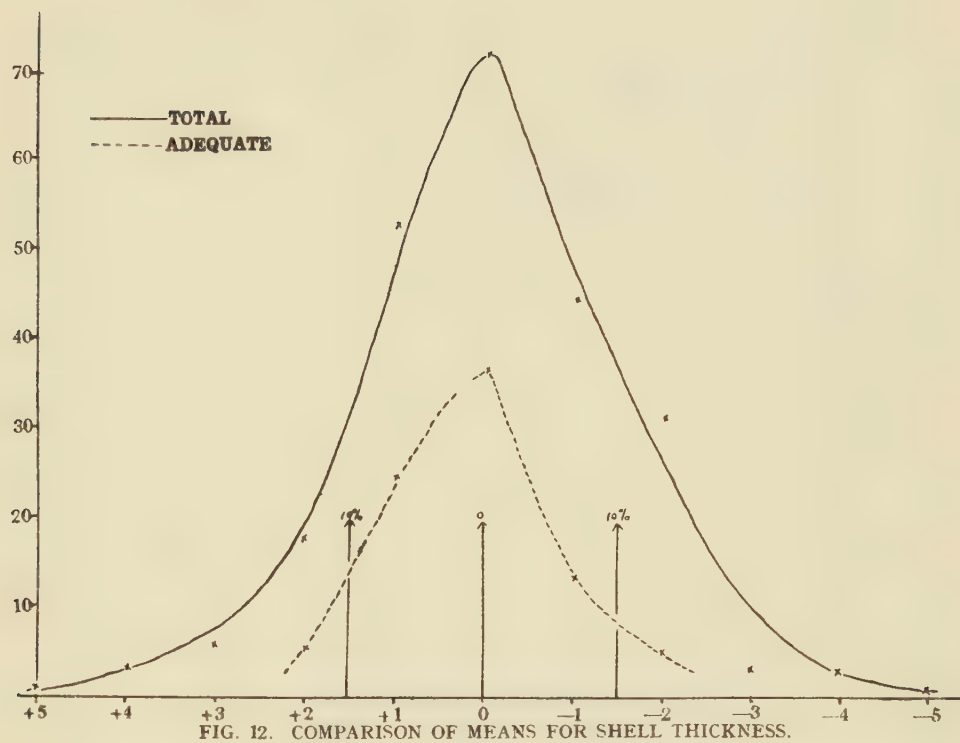


FIG. 11. COMPARISON OF MEANS FOR POD DIAMETER.



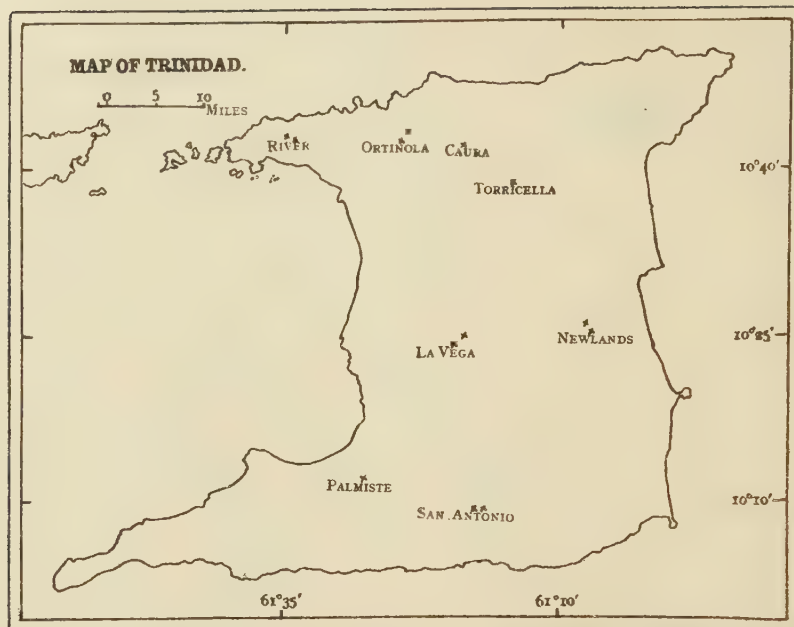
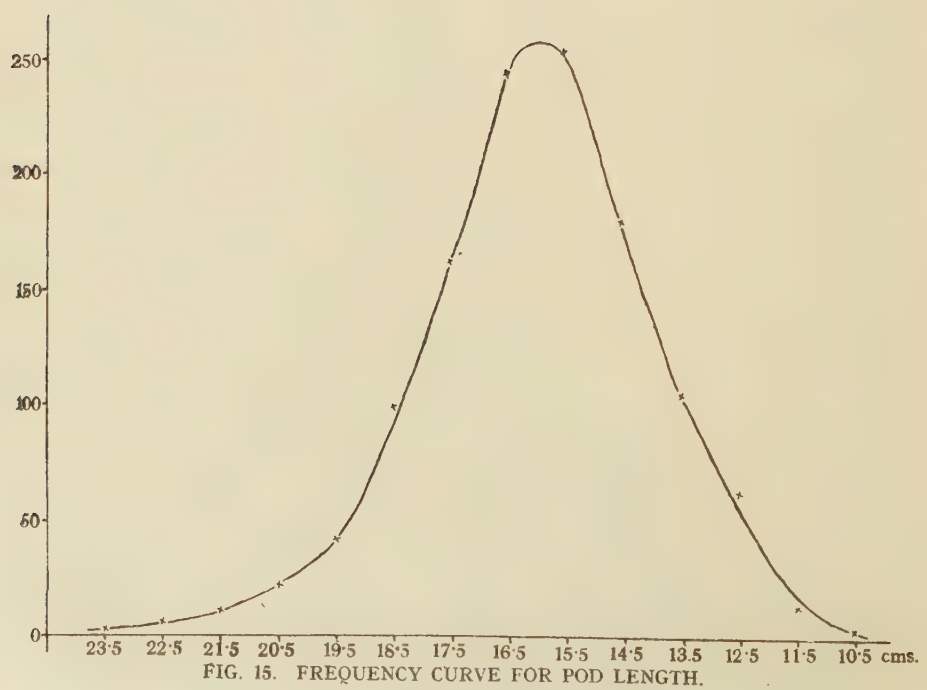


FIG. 14. OUTLINE MAP OF TRINIDAD SHOWING STATIONS WHERE TREES WERE EXAMINED.



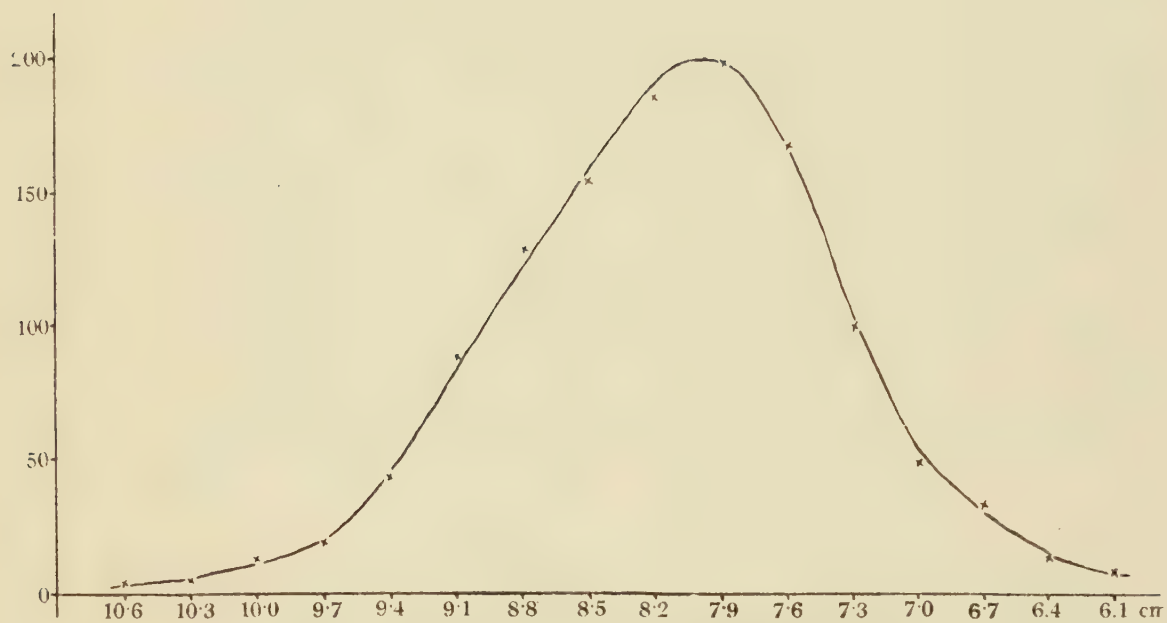


FIG. 16. FREQUENCY CURVE FOR POD DIAMETER.

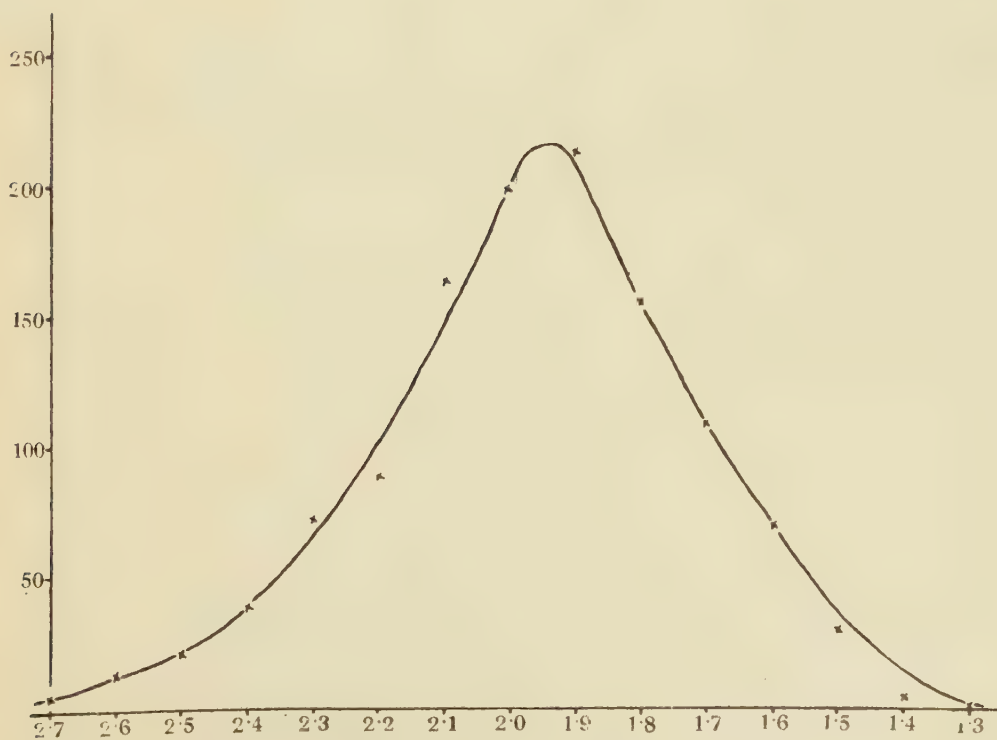


FIG. 17. FREQUENCY CURVE FOR MEAN POD RATIO.

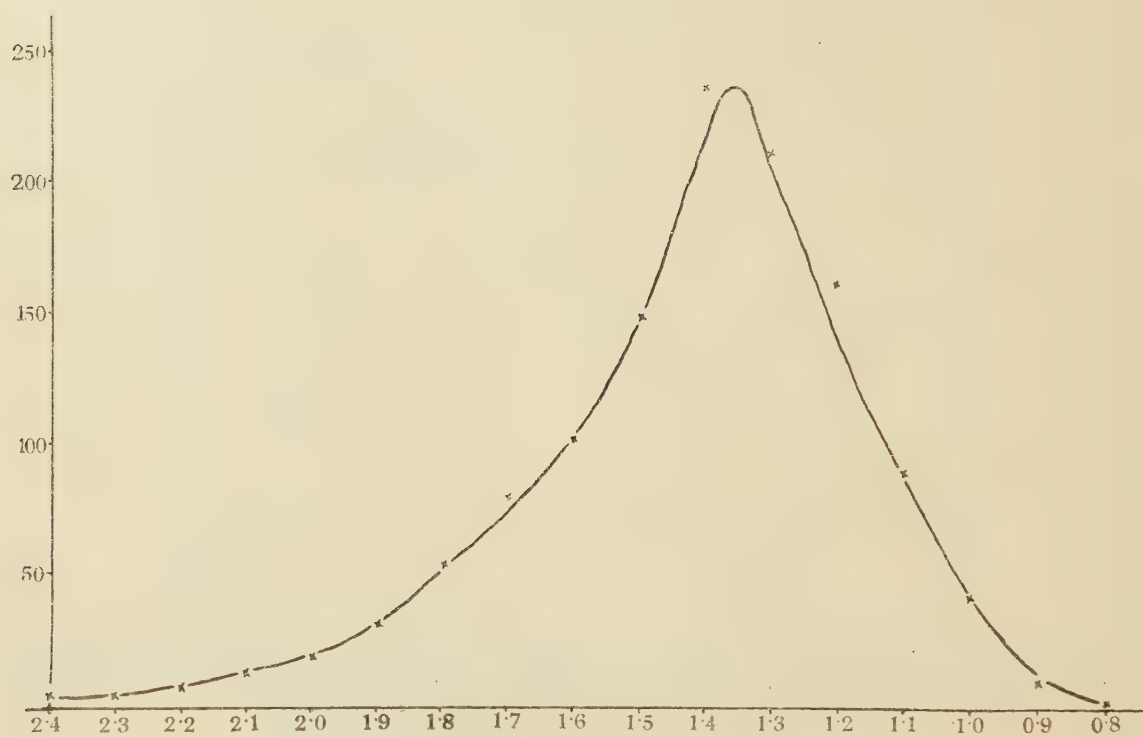


FIG. 18. FREQUENCY CURVE FOR SHELL THICKNESS.

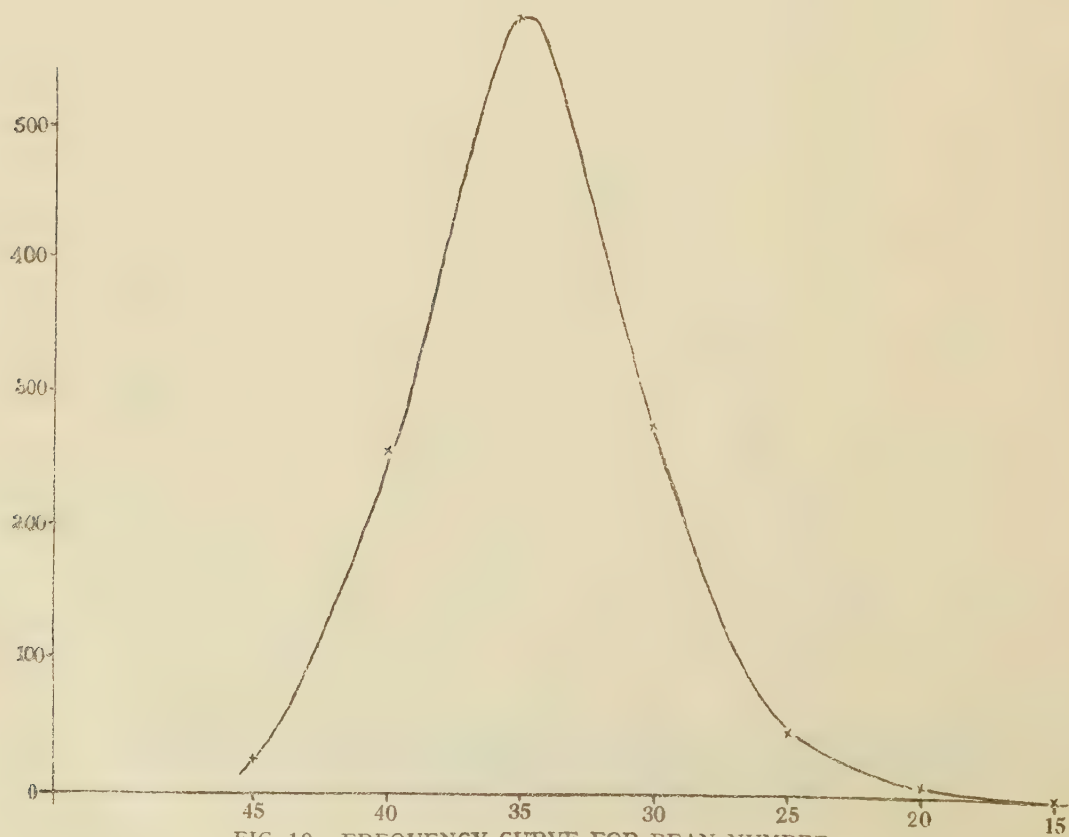


FIG. 19. FREQUENCY CURVE FOR BEAN NUMBER.

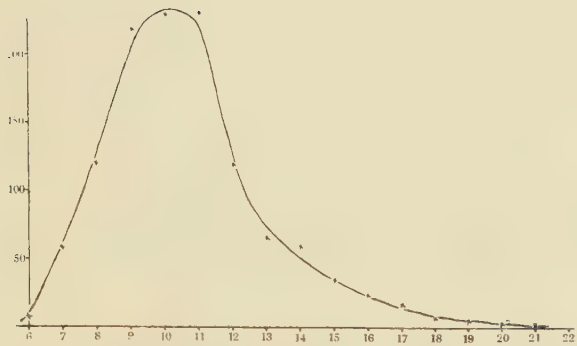


FIG. 20. FREQUENCY CURVE FOR PODS TO THE POUND.

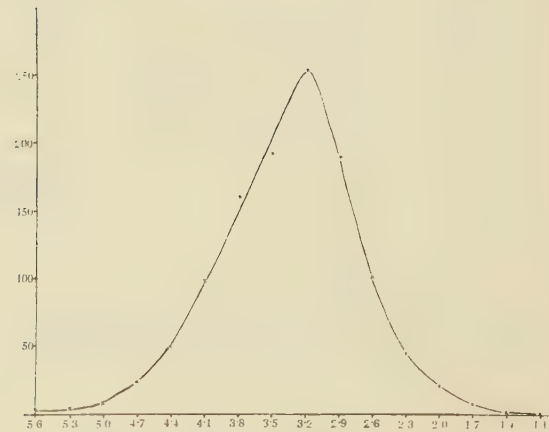


FIG. 21. FREQUENCY CURVE OF WEIGHT OF A SINGLE BEAN.

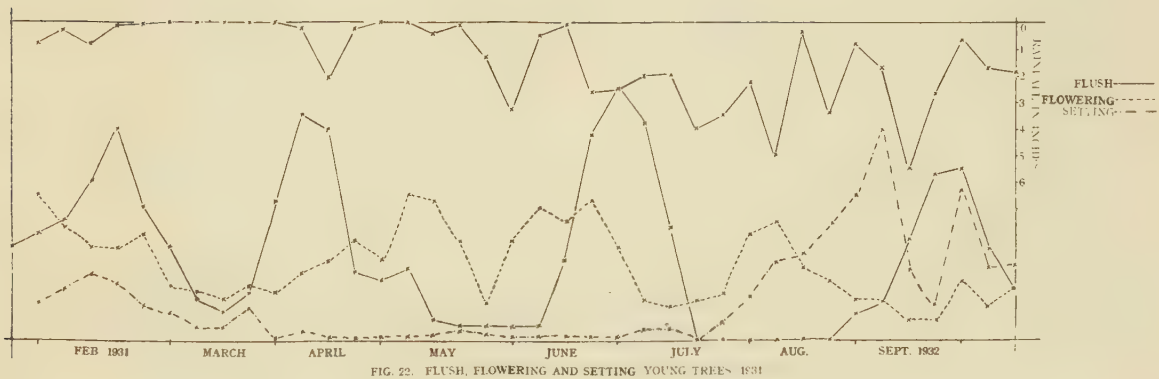


FIG. 22. FLUSH, FLOWERING AND SETTING YOUNG TREES 1931.

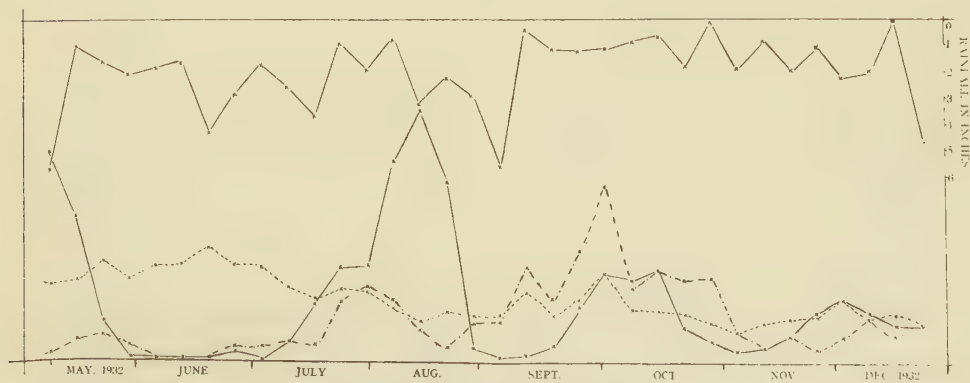


FIG. 23. FLUSH, FLOWERING AND SETTING YOUNG TREES, 1932.

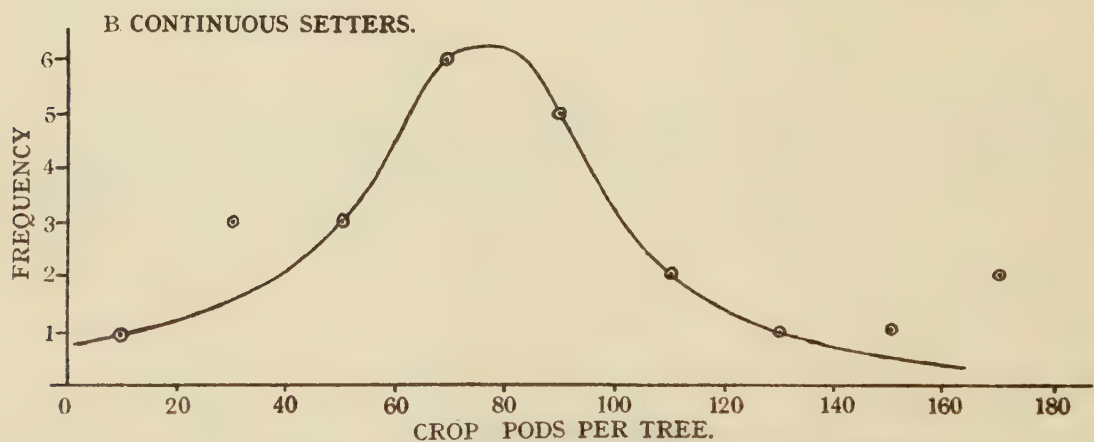
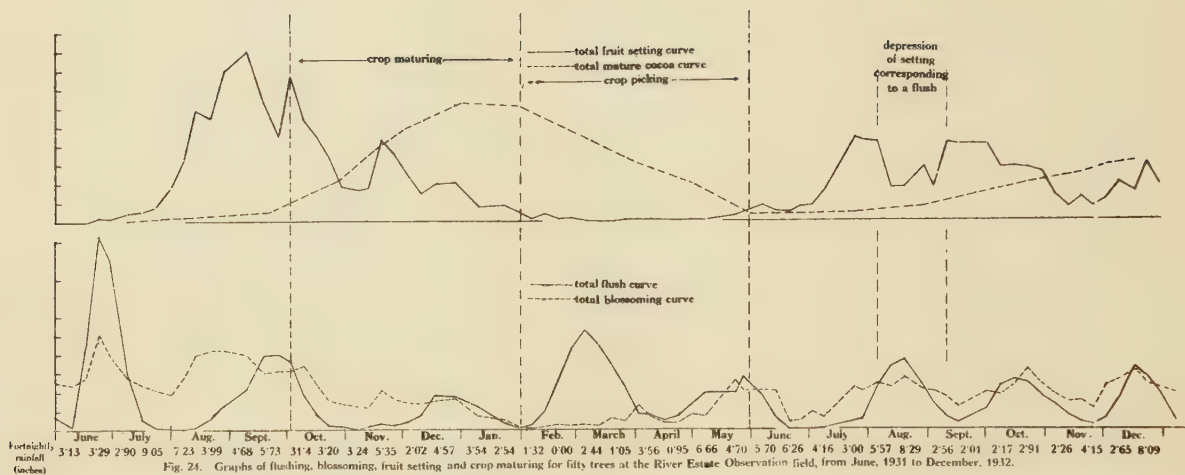


FIG. 25. DISTRIBUTION OF YIELD OF 24 CONTINUOUS SETTERS.

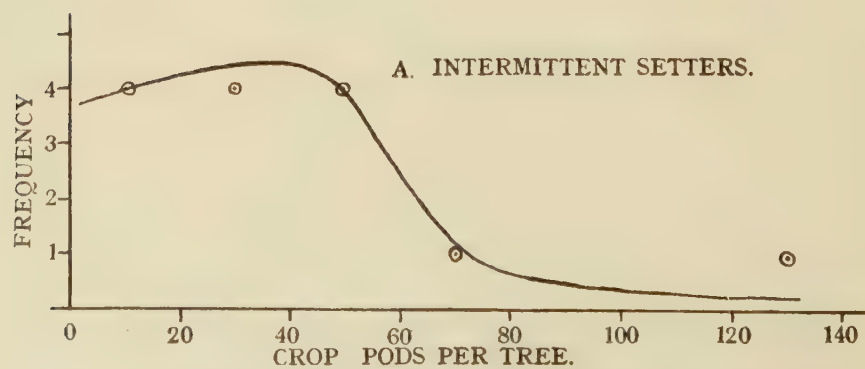


FIG. 26. DISTRIBUTION OF YIELD OF 14 INTERMITTENT SETTERS.

B.—CHEMICAL AND ECOLOGICAL SECTION.**THE CHEMICAL PROGRAMME OF 1932.**

By F. HARDY, M.A.

THE main lines of investigation described in the First Annual Report (for 1931) have been rigorously followed. They concern (1) an environmental study of the cacao tree, and (2) a soil survey of part of the Central Range area of Trinidad. In addition, new lines of work have developed during the past year, concerning (3) the phosphate status of the cacao soils of Trinidad, Tobago and Grenada, (4) the nitrogen status of these cacao soils, and (5) the relationship between the chemical composition of cacao leaves and beans, and environmental growth conditions, including the general nutrient status of the soil.

(1) Environmental Study.

With the end of 1932, an important stage of work under this heading has been reached, when definite conclusions regarding the effect of weather and general soil conditions on the growth processes of the cacao tree, may tentatively be advanced. These results are discussed by Mr. McDonald in Part I of the report which follows. The environmental studies will be continued as a matter of routine, in order further to establish confidence in the findings. Besides their intrinsic value, the environmental data have bearing on the prosecution of other more detailed investigations that are being carried out in the neighbourhood of the two contrasted plots.

(2) Soil Surveys.

The ultimate object of the survey work, which has been performed in 1931 and 1932, is the determination of all those factors, both physical and chemical, that characterise a good cacao soil, and contrast it with a bad. Broad soil surveys of this nature should aid very materially in determining the requirements of the cacao tree under different combinations of climatic and soil factors.

(3) Phosphate Status.

An important outcome of our cacao soil survey work, both in the Central Range of Trinidad, and in Tobago and Grenada, is the discovery that the available phosphate content of West Indies cacao soils appears to be a major soil factor limiting productivity. Consequently, a number of manurial experiments, designed according to the recommendations of the Field Experiments Committee, and laid down with the co-operation of the Trinidad Department of Agriculture, has been initiated in Trinidad and in Grenada, in order to test the effect of soluble phosphatic manure on the yield of cacao.

The chemical methods usually applied to determine content of available phosphate in soil sometimes give unreliable results, or are somewhat tedious and lengthy. Accordingly, a sensitive biological method of gauging the phosphate status of a soil by growing tomato seedlings in pots has been examined. The technique of this method is simple and furnishes a ready means whereby the planter can test his own soils without recourse to chemical reagents.

(4) Nitrogen Status.

During 1932, an attempt has been made to follow the fluctuations in the soluble nitrogen fraction of cacao soils at the two ecological plots. No entirely satisfactory method has yet been evolved for measuring available nitrogen at a given instant, but various procedures are being further tested. In connection with this work, the effects of mulching with heavy dressings of vegetable matter (brushings and leaves) on nitrogen status, as well as on soil moisture and soil temperature, are being investigated. The response of the tree to mulching (which has given marked increases in yields in certain experiments in Dominica) will be assessed on field plots.

(5) Chemical Composition of the Cacao Tree.

Following the example of the Agricultural and Horticultural Research Station at Long Ashton, Bristol, England, a start has been made in an investigation of the effect of environmental factors on the composition of the leaves and of the beans of cacao trees growing in different environments. The work so far has been confined to analyses of material collected from the two contrasted ecological plots. It is intended later to examine the effect of mineral nutrients in replicated tub-cultures of pure quartz-sand, to which dilute solutions, lacking one nutrient element (nitrogen, phosphorus, potassium, calcium, magnesium), will be systematically added. Preliminary trials have already shown that cacao can be grown in nutrient sand-culture from seed, but in the new experiments, an attempt will be made to establish cuttings from a single tree, which Prof. Cheesman and Mr. Pyke have kindly agreed to supply.

The results so far accumulated from chemical analyses of cacao leaves appear to have important bearing on the problem of *Thrips* attack. It is hoped later to test some of these findings by means of specific field experiments. An account of the work to date is given by Mr. McDonald in Part III, Section III, of his report.

Analyses of cacao *beans* have shown differences in composition between material collected from the two ecological plots, but these differences may be due to the different varieties of cacao growing there; the good plot cacao is the Forastero type, but the bad plot cacao approaches the Calabacillo type. Urgent need therefore arises (if this work is to yield comparable results) for the establishment of areas of strictly genetically-similar cacao trees, exposed to different growth environments.

Studies of the chemical composition of the plant in relation to its environment, such as have been prosecuted in different countries where different crops are grown, emphasises the importance of a *balanced ratio* of nutrient elements, which may be specific for a particular crop giving maximum yield. Thus, Carmargo has recently shown that a definite ratio of

potassium to nitrogen in the soil is required for optimum growth by the young *coffee* plant. Increase of potash or of nitrogen above this ratio resulted in diminished growth, but addition of phosphate, even in considerable excess, exerted no harmful effects. Phosphate appears to be the element which has the most marked influence on the development of roots, stems and leaves of coffee, and perhaps the same circumstance applies to cacao. It would seem therefore that investigations on the inter-relationships between the three important nutrient elements (nitrogen, phosphorus and potassium), which are concerned in the growth of the cacao tree, are eminently worth while, and their pursuance should, in due course, yield results of considerable practical importance.

29th March, 1933.

PART I.

AN ENVIRONMENTAL STUDY OF THE CACAO TREE.

BY J. A. McDONALD, A.I.C.T.A.

1.—Introduction.

SINCE the beginning of January, 1931, regular observations of a number of environmental factors have been carried out on two selected cacao plots which are representative of a good and a bad cacao environment respectively. In the First Annual Report on Cacao Research, 1931, the factors studied and the methods of observation were described in detail. The results of one year's observations were discussed, and it was indicated (i) that definite relationships exist between environmental moisture conditions and the growth and behaviour of the cacao tree, (ii) that characteristic differences occur in the environmental conditions between the good plot and the bad plot.

The two years' results now at our disposal will be discussed under the above two headings.

2.—Relationship Between Environmental Conditions and the Growth and Yield of the Cacao Tree.

(A) RELATION OF WEATHER TO GENERAL GROWTH CONDITIONS.

The records up to December, 1932, for relative humidity, soil moisture and rainfall, are graphically presented in Figs.* I and II. From a study of these records, the following relationships are indicated;

(a) Growth flushes, accompanied by change of leaf, coincide with the onset of drier conditions following a wet spell (fall in atmospheric humidity).

(b) Growth flushes, unaccompanied by change of leaf (*i.e.*, additional new vegetative growth), coincide with a wet spell following dry weather (rise in soil moisture).

* All figures mentioned in text will be found following page xii.

(c) Flowering and setting of fruit occur during a period of *uniformly* high moisture conditions.

(d) Many pods of all sizes turn black on the trees during periods of excessively high moisture conditions.

(B) EFFECTS OF WEATHER CONDITIONS ON YIELD.

(1) *Setting and Development of Fruit.*

The records show that the chief period of flowering, setting, and development of young fruit, occurs during a period of high moisture conditions, which extends uniformly over a duration of about three months. If a short dry spell of two to three weeks duration occurs, a flush of vegetative growth may be induced, and then, not only is flowering and setting temporarily checked, but many young *cherelles* shrivel on the trees.

At the other extreme, excessive moisture conditions cause fruit of all sizes to turn black on the trees. In this respect, November to December appears to be a critical period; during this time, the trees carry their full leaf canopy, but even when rainfall is light, the humidity of the air remains at a high level (November, 1932).

The records indicate that in Trinidad there are two main periods in the year when the cacao crop may be produced, *i.e.* :—

(1) Mid-June to mid-September.

(2) Mid-October to mid-January.

These two periods are normally divided by a dry spell of three to four weeks' duration (the "*petit carême*"), which generally occurs in September or October. In studying the relationship of weather conditions to the production of the cacao crop, due consideration should be

given to extreme weather conditions or sudden fluctuations, which tend to break up or shorten these two main periods of setting. Critical periods are indicated as follows:—

(1) The dry season, January to May (*see* records for bad plot, 1931; where the first period of setting was considerably shortened by excessively dry conditions in March, April, May).

(2) November and December (excessive humidity).

(3) October and November (Thrips attack, *see* next section).

(2) *Thrips* Attack.

An important factor which has bearing on the yield of cacao in Trinidad is the attack of the sucking insect, *Heliothrips rubrocineta*, known as Thrips. Attacks of Thrips, which generally occur during the latter part of the year (October and November), appear to be definitely connected with changes in the weather. Thrips attacks have occurred in the immediate neighbourhood of both plots during the past two years at the following times:—

Bad Plot.—November, 1931, and November, 1932.

Good Plot.—November, 1932 (Severe).

A study of the records shows that these attacks in all cases have been associated definitely with a fall in soil moisture, while atmospheric humidity has remained at a comparatively high level.

(C) RELATIONSHIP OF RAINFALL TO ENVIRONMENTAL CONDITIONS.

Since rainfall is the most easily and most commonly measured of climatic factors, many attempts have been made in the past to correlate the yield of cacao with rainfall (1, 2, 3, 4, 5), but no really consistent correlations have so far been obtained. Consideration of the foregoing records indicates the difficulty of obtaining such correlations. Rainfall records alone do not give an accurate measure of the moisture status of a particular environment, even when duration is also considered (*e.g.*, total rain multiplied by rainy days). Other factors, such as wind, sunshine and humidity of the air, also play an important part in deciding environmental moisture conditions.

Our records indicate that the cacao tree is particularly sensitive to fluctuations in environmental conditions, and in studying such fluctuations, rainfall returns are particularly difficult to interpret. For instance, two consecutive fortnightly periods may show a rainfall of 2.00 and 8.00 inches respectively, and, although the rainfall shows a fourfold increase, humidity of the atmosphere and soil moisture may change but little during these periods. In ecological investigations, it is the *effect* of rainfall which has to be considered, rather than the magnitude of the rainfall, and the relationships which have been demonstrated are based largely on records of atmospheric humidity and soil moisture. There is, of course, a considerable degree of relationship between rainfall and factors such

as soil moisture and atmospheric humidity; the difficulty is to devise some method of considering rainfall returns so that they will give a true picture of environmental conditions. In Figs. I and II, weekly rainfall returns have been considered, and a five-weeks' moving average has been plotted, since the five-weeks' period eliminates the extreme short-time fluctuations, and yet stresses the effect of dry or wet spells of about three weeks' duration, such as appear to be important (*see* above (B)). It is not suggested that the method adopted is the best method of regarding rainfall returns in relation to cacao environmental conditions in Trinidad. At an early date, it is intended to consider in more detail all the meteorological data which have so far been collected, in order to obtain more definite evidence on this question.

3.—The Characteristics of a Good Cacao Environment.

In the 1931 report, the different environmental factors were discussed in detail, and the differences between the good environment and the bad environment were indicated. These differences were shown to be more marked during the dry season. The data collected during 1932 have served to confirm our previous findings. During 1932, however, there was no marked dry season, and therefore the differences in environmental conditions between the two plots were not so pronounced as in 1931.

A. S. Thomas (6) has compared the rainfall of a number of different localities in the Gold Coast, and has shown that the dry season is a critical period as far as the growth of cacao is concerned. Under Trinidad conditions, this is often the case, but unsuitable localities may also suffer from excessive moisture conditions during periods of high rainfall.

Comparative records for the two plots have been set out in a number of graphs (Figs. III-VII). From a study of these records, the following general statement may be made: *it is characteristic of the good plot that its environment is not subject to such sudden or such extreme fluctuations as the bad plot, particularly with respect to the moisture status of the soil and atmosphere.* Fluctuations in environmental conditions are caused primarily by changes in the weather, but climatic changes may be modified to a certain extent by factors such as shade and shelter. Indeed, it seems probable that the chief function of shade trees grown in a cacao field is to act as a buffer against fluctuations in environmental conditions. On this question, our records give interesting indications, as follows:—

Effect of shade. At the good plot, the tops of the cacao trees are more lightly shaded (Fig. VI); and solar radiation is greater at all times, but, during the only dry spell recorded (February to May, 1931) the tops of the cacao trees were better sheltered (Fig. V) and evaporation was less. During wet

weather, atmospheric humidity tends to be higher at the *bad* plot than at the good plot, and it would seem therefore that the bad plot is too heavily shaded, causing increased damage from excessive humidity during wet weather, but not adequately sheltered from the wind during dry spells. These findings indicate that the cacao tree requires adequate *shelter* from the wind, but on the other hand excessive *shade* may be detrimental. Meteorological methods, such as have been employed in our environmental studies, should therefore serve to test any given locality about which critical information is desired on these points.

4.—Summary.

(1) Meteorological and environmental data, collected from two representative "good" and "bad" cacao plots for a period of two years, are graphically presented.

(2) Growth flushes and change of leaf on cacao are shown to coincide with definite changes in environmental moisture conditions.

(3) A number of relationships between weather conditions and the production of the cacao crop have been indicated.

(4) The relationship between rainfall and yield of cacao is briefly discussed.

(5) The good cacao plot has shown characteristic differences in the moisture status of its environment from the bad cacao plot.

(6) These differences are more pronounced during dry weather.

(7) Extreme fluctuations in environmental conditions characterise the bad plot.

(8) The function of shade and shelter in modifying climatic fluctuations is discussed.

5.—References.

- (1) Auchinleck, G. G., and Knowles, C. H. Yields of Cacao on Experiment Stations. *Gold Coast Dept. Agric.*, Bull. 4, p. 44, 1926.
- (2) Dunlop, W. R. Rainfall and Crop Yield, with Particular Reference to Cacao in Trinidad. *Trop. Agriculture*, II, p. 109, 1925.
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- (5) Skidmore, C. L. Indications of Existence of Correlation between Rainfall and Number of Cacao Pods Harvested. *Gold Coast Dept. Agric. Year Book*, 1928. p. 114.
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PART II.

A SURVEY OF SOME TRINIDAD CACAO SOILS.

By J. A. McDONALD, A.I.C.T.A.

(1) Introduction.

The soil survey which has been carried out during the past two years, was initiated with the main object of investigating the chief characteristics of some typical Trinidad cacao soils, and in sorting out those factors which differentiated good cacao soils from bad cacao soils. In the First Annual Report on Cacao Research, 1931, a preliminary account of the main soil types of the Gran Couva District was presented, and it was shown that there were certain chemical factors which distinguished good cacao soils from bad cacao soils in this area.

(2) Outline of Year's Work, 1932.

During 1932, the survey was continued, and the whole of the intended Central Range area has now been mapped. A number of further soil samples have been collected, and these samples are at present being examined by the analytical staff of the College Chemistry Depart-

ment. There is no object at present in giving a detailed account of the work carried out during 1932. When all the analytical data have been collected, a detailed account of the survey of this area of cacao soils will be prepared.

Recent surveys (1, 2) carried out by the College Department of Chemistry, of the cacao soils of Trinidad, Tobago and Grenada, have indicated that a high available phosphate content, and a high carbon/nitrogen ratio, appear to be important factors clearly distinguishing good cacao soils from bad. In the 1931 report, it was pointed out that these two factors are also important for the Central Range area. No significant difference could be demonstrated with regard to certain other factors, such as reaction (acidity or alkalinity of soil), available potash, total nitrogen and total organic matter. Soil texture also appeared to be unimportant within certain limits, good-yielding cacao being found on soils which varied from sands to silty clays.

In view of these findings, a more detailed study of the relationship between various soil factors and the productivity of cacao soils was undertaken by A. R. Foster (3), Post-graduate Student, during the 1931-32 session. Foster's primary requirement for this investigation was a number of estates situated on various soil types, where accurate records of the yield of individual fields were available. This proved to be the limiting factor in the investigation, because there were very few estates where such records have been kept. La Vega and San Salvador Estates were eventually selected. Foster's results may be briefly summarised as follows:—

(a) No definite correlation could be demonstrated between any *one* soil factor and yield.

(b) There was no evidence for the soils examined that the carbon/nitrogen ratio of the organic matter in the soil is a definite controlling factor in the yield.

(c) The three lowest-yielding fields had very low available phosphate contents.

These results appear at first sight to contradict previous findings, but they are in reality easily explained. Although the fields differ considerably in yield, all except two fall in the category of "good" cacao soils, that is, they have a yield of over 8 bags per 1,000 trees. Of the other two fields, Reäl (La Vega), although it falls in the bad soil category, has a fair average yield of 7.8 bags per 1,000 trees. The other bad field is exceptional in that its poor condition is probably due in large part to the poor water relations of the soil type (Brasso Clay) on which it is situated. Foster's investigation therefore has shown that *within a group of good cacao soils*, no one factor can be said to be directly related to differences in yield. From his tabulated results, he has outlined certain factors which are characteristic of good cacao soils.

(3) Water Relationships of Cacao Soils.

In Part I of this report, it was shown that one of the main findings of our environmental study was that the cacao tree is particularly sensitive to sudden or extreme fluctuations in its environment, particularly with respect to moisture conditions. During the course of the present soil survey, field evidence has been obtained which adequately confirms this generalisation as far as the soil is concerned. On all soil types investigated, it has been evident that, apart from any difference in chemical factors, the water relationships of the soil are of the utmost importance in deciding whether a soil will support good cacao cultivation or not. Within the Brasso Clay soil type, during periods of severe drought, large patches of cacao are liable to die out completely. This soil is a silty clay containing a small amount of sand (9 per cent.), and it is underlain by a very

impervious blue clay; it is therefore liable to become waterlogged during wet weather, and during dry weather it dries out to a harmful extent. Undoubtedly these unsatisfactory water relationships are largely responsible for some of the very poor cacao cultivation which exists on the Brasso Clay soil. Within the area surveyed during 1932, large areas of unproductive sandy soils occur, usually over undulating country. The hill tops are seldom cultivated, but along the banks of streams, and for a short distance up the slopes, there is generally fair cacao cultivation. In these rather loose sandy soils, moisture also appears to be a limiting factor in the growth of cacao. Similar conditions are found in the Caroni Red Clay soil type (Talparo clay), where cacao seldom thrives on hill tops, or on steep slopes, but fair cultivation exists in sheltered valleys and along the banks of streams.

On the other hand, within the Chocolate Soil type (which is the best cacao soil we have so far examined) moisture conditions are almost ideal. The soil is a clay loam (I.T. 42), containing a large amount of sand (40 per cent.), together with a fair amount of clay (M.P.S. 50 per cent.). The Chocolate Soil is underlain by a porous, calcareous, brown sandstone. It is therefore very free-draining in wet weather, and yet very retentive of moisture during dry weather.

When these observations are considered together with the evidence obtained from our ecological study, it is evident that one of the primary requirements of a good cacao soil is an even moisture status, that is, the soil must not be liable to wide fluctuations in its moisture content.

(4) Summary.

(1) A brief outline of the soil survey work carried out during 1932 is presented.

(2) The water relationships of cacao soils are discussed on the basis of field evidence.

(3) Field observations over a wide area have shown that an even moisture status is one of the chief characteristics of a good cacao soil.

(5) References.

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- (2) Hardy, F., McDonald, J. A., and Rodriguez, G.—Studies in West Indian Soils (IV). The Cacao Soils of Grenada. Supplement to *Trop. Agriculture*, Vol. IX, 1932.
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PART III.

PROGRESS OF SOME DETAILED INVESTIGATIONS.

BY J. A. McDONALD, A.I.C.T.A.

General Introduction.

In addition to the broad lines of research described in Parts I and II of this report, a number of more detailed problems are at present under investigation. In this section, a brief account of these problems will be given.

I.—THE PHOSPHATE STATUS OF CACAO SOILS.

(A)—MANURIAL EXPERIMENTS.

In Part II of this report, it was pointed out that one of the main findings of our cacao soil surveys was that the available phosphate content of the soil appears to have an important bearing on the productivity of the cacao tree. Accordingly, manurial experiments have been laid down on four different soil types for which previous data have indicated a deficiency in available phosphate. The soil types are:—(a) Sandy alluvium (River Estate and Torrecilla Estates, Northern Range Valleys, Trinidad), (b) Silty-clay alluvium (Las Hermanas Estate, Caroni Plain, Trinidad), (c) Brasso Clay (Santa Severa Estate, Central Range, Trinidad), (d) Red earth soil (Carriere Estate, Grenada). Each of these experiments has been set out in the form of a Latin Square, suggested by the work of Cheesman and Pound (1), and approved by the Field Experiments Committee. The lay-out is designed to test the effect of different quantities of soluble

phosphatic manure on the yield of cacao. The records so far obtained are insufficient to merit further discussion at this point.

(B) POT TEST FOR PHOSPHATE DEFICIENCY.

A sensitive pot test for indicating phosphate deficiency in soils has been evolved. This test depends on the peculiar sensitivity of the young Tomato plant to phosphate deficiency. It offers a method by which the practical man can test his soils for phosphate deficiency without recourse to laboratory methods. A full account of the technique of the test and results obtained with some Trinidad cacao soils has been published elsewhere (2).

References.

- (1) Cheesman, E. E., and Pound, F. J. Uniformity Trials on Cacao. *Trop. Agriculture*, Vol. IX, No. 9, p. 277, 1932.
- (2) McDonald, J. A. A Sensitive Pot Test for Phosphate Deficiency in Soils. *Trop. Agriculture*, Vol. X, No. 4, p. 108, 1933.

II.—THE NITROGEN STATUS OF CACAO SOILS.

(1) Introduction.

It has recently been shown by Hardy and others (1) that there is an important relationship between the Carbon/Nitrogen ratio of soil organic matter and the productivity of cacao soils. It has also been shown by many plant physiologists (2) (3) that the behaviour of plants with regard to growth and reproduction depends to a considerable extent on the relative proportions of carbohydrates and nitrogen within the plant, the theory being that, when the value of the carbohydrate/nitrogen ratio is relatively small, vegetative activities follow, but if the value of this ratio is relatively large, reproduction takes place. If the carbohydrate/nitrogen ratio attains a very high value (due to abundant carbohydrates and scarcity of nitrogen) reproductive as well as vegetative activities may cease.

The present investigation therefore was initiated in an attempt to trace the fluctuations in the various soluble nitrogen fractions of the soil, and the effects which variations in the quantity of available soil nitrogen might exert on the growth and behaviour of the cacao tree.

(2) Methods of Sampling and General Procedure.

Measurements of nitrate content and total soluble nutrients (as shown by electrical conductivity of aqueous soil extracts) were made on soil samples taken fortnightly from the two ecological plots as follows:—(a) Fresh soil samples, (b) Samples stored for six weeks at field moisture content, (c) Samples air-dried and stored for six weeks at half-saturation capacity. Ammonia determinations were also made on a certain number of the fresh samples. Nitrate determinations on the stored samples give an indication of the ability of the soil micro-organisms to produce nitrate from the soil organic matter. Conductivity measurements indicate the amount of total water-soluble components present (including nitrates), and it was thought that some relationship would be shown between conductivity values and nitrate contents.

(3) Results.

The data so far obtained are presented in Table I and Table II, and in Fig. VIII. In Table II, variations in nitrate content with depth of sample are shown. The results indicate

Table I.

Comparison of Soils with regard to Nitrate content and Conductivity values.

Sample Top 6-inch Layer.	Time of Sampling.	Determination	D.F.	GOOD PLOT.		BAD PLOT.		Test of Significance.
				Mean.	Variance.	Mean	Variance.	
Fresh Soil .. Soil stored at Field Moisture Content	Wet Season	Nitrates	39	13.0	154	16.6	179	1.25 Not Sig.
	Wet Season	Nitrates	13	48.0	280	53.0	180	0.88 Not Sig.
	Wet Season	Conductivity	21	114	1869	147	3550	2.10 Fairly Sig.
	Dry Season	Conductivity	7	124	1240	153	775	1.27 Not Sig.
Soil Air-dried and Stored at half Saturation Capacity	Wet Season	Nitrates	38	105	1072	61	790	6.9 Def. Sig.
	Wet Season	Conductivity	21	230	3892	132	1274	6.8 Def. Sig.
	Dry Season	Conductivity	7	125	700	156	872	1.59 Not Sig.

Table II.

Comparison of the Differences of the Mean Nitrate content with depth of Sample.

		Depth of Sample.	Nitrate p.p.m.	D.F.	Variance.	Test of Significance t.
Fresh Samples ..	1	1st 6 inches	15	16	332	(1-2) 1.17 Not Sig.
	2	2nd 6 inches	10	16	46	(2-3) 1.22 Not Sig.
	3	2nd foot	8	16	10	(1-3) 1.77 Not Sig.
Stored Samples (Nitrifying ability)	4	1st 6 inches	92	14	735	(4-5) 7.1 Def. Sig.
	5	2nd 6 inches	33	14	337	(5-6) 4.8 Def. Sig.
	6	2nd foot	15	14	37	

that the formation of nitrate takes place chiefly in the top six-inch layer of soil. In Table I, all the data for the top six-inch layer of soil are compared, and certain differences between the good plot soil and the bad plot soil are indicated as follows:—

(A) NITRATES.

(a) The mean nitrate content of the bad plot soil is slightly higher than the mean nitrate content of the good plot soil, but the difference is not significant.

(b) When the soil samples were stored at field moisture content, there was no significant difference in the nitrifying ability of the two soils.

(c) When the soil samples were air-dried, and subsequently stored at half-saturation capacity, the nitrifying ability of the good plot soil was far greater than the nitrifying ability of the bad plot soil; *i.e.*, air-drying had a much greater stimulating effect on the nitrifying organisms of the good plot soil.

(d) No definite seasonal nitrate fluctuations can be detected (Fig. VIII). This may be due

to the fact that there has been no long spell of dry weather, during the eighteen months for which nitrate determinations have been made.

(e) Nitrate content of the fresh samples has been generally low for both plots, but it is interesting to note that the highest values obtained have been found in samples taken in June and July, 1931, during the first rains following the long dry season of 1931.

(f) The nitrate contents of the second six-inch layer and the second foot of soil are generally lower than those of the top six-inch layer, but these differences are not statistically significant.

(g) The nitrifying ability of the second six-inch layer and of the second foot of soil are definitely much lower than that of the first six-inch layer (Table II).

(B) ELECTRICAL CONDUCTIVITIES.

(a) The conductivity values of the fresh samples fluctuate within wide limits. There is a good degree of correlation between the electrical conductivity values and the nitrate content of the fresh soil samples (top six-inch layer), *i.e.*, Good plot soil ($R = +0.914 \pm 0.018$; bad plot soil, $R = +0.88 \pm 0.032$).

(b) There is no direct relationship between electrical conductivity values and nitrate contents of the stored soil samples (Fig. VIII), but high peak values for conductivity coincide with high peak values for nitrate content.

(c) The conductivity values of the stored samples show that air drying has the effect of greatly increasing the amount of water-soluble components in the good plot soil. Air drying has no significant effect on the total water-soluble components of the bad plot soil (Table I).

(C) AMMONIA.

Determinations of the ammonia content of the soil were carried out on a number of the fresh samples. The results are presented in Table III.

Table III.

Date.	AMMONIA NITROGEN (P.P.M.)	
	Good Plot.	Bad Plot.
20-9-32	7	4
18-10-32	8	3
2-11-32	3	2
15-11-32	3	3

These results indicate that ammonia does not accumulate to any appreciable extent in these two cacao soils, but it must be remembered that no samples taken during dry weather have been examined.

(4) Discussion.

From the results obtained, it has been shown that both the cacao soils (good plot and bad plot) show adequate ability to produce nitrates from soil organic matter, even though the residual nitrate content of the fresh soil is generally low. It has not been possible to trace any definite seasonal fluctuations in the soluble nitrogen fractions of the soils, but it is of interest to note that samples taken during the first rains following the 1931 dry season showed a very high nitrate content. This period corresponded with a time of marked vegetative activity on the part of the cacao tree.

The general results obtained have indicated that measurement of the nitrate content of the fresh soil during wet weather does not give an accurate representation of the nitrate status of the soil at that particular time. The consistently low values obtained are probably due (1) to rapid removal by the actively growing trees, and (2) to rapid leaching. In an investigation of this nature, where an attempt is being made to trace the amount of nitrogen available to the plant throughout the season, it is probable that

measurements of the *nitrifying ability* of the soil give a more reliable indication of the available nitrogen status of the soil. In continuing this investigation, a number of different methods for measuring the nitrifying ability of soil are being examined. Certain of the results have indicated that air-drying has a definitely stimulating effect on the nitrifying organisms of the soil; this is of interest in that it indicates that a spell of dry weather, such as a dry season in Trinidad, may be followed by a period of abundance of available nitrogen.

It is intended that this investigation should be linked up with work which is being conducted on the chemical composition of cacao leaves (described in Section III); it is thought that periodic measurement of carbohydrates and nitrogen in the leaf may give more reliable information concerning the uptake of nitrogen by the tree, and its influence on growth. Also, in connection with this problem, the effect of *mulching* on the growth and yield of the cacao tree, and its effect on soil moisture, soil temperature, micro-organic activity and available nitrogen supplies, is being investigated. A number of mulched areas and suitable control plots have already been laid down.

(5) Summary.

(1) Fluctuations in the nitrate and ammonia content of two contrasted (good and bad) cacao soils have been measured.

(2) The results have not shown any definite seasonal fluctuations in the nitrate content of the soil, due perhaps, to the uniformly wet weather experienced.

(3) The nitrate content of both soils is generally low, but both soils show adequate ability to form nitrate from soil organic matter.

(4) Air-drying greatly increases the nitrifying ability of the good plot soil.

(5) The formation of nitrates is confined mainly to the top six-inch layer of soil.

(6) Relationships between values for electrical conductivity of aqueous soil extracts and the nitrate contents of the soils have been demonstrated.

(6) References.

- (1) Hardy, F., and Griffiths, G. Carbon/Nitrogen Ratios in Cacao Soils. *Nature*, No. 3247, Vol. 129, p. 132, 1932.
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- (3) Fischer, H. Zur Frage der Kohlensaure-Ernahrung der Pflanzen. *Gartenflora*, 65, p. 232, 1916.

III.—CHEMICAL COMPOSITION OF THE LEAVES OF CACAO IN RELATION TO ENVIRONMENTAL GROWTH CONDITIONS, AND WITH SPECIAL REFERENCE TO THRIPS ATTACK.

(1) Introduction.

Recent investigations of the nutrient relations of fruit trees have demonstrated that many physiological affections may definitely be traced to lack of balance between various nutrient elements. Thus, Wallace (1, 2) has shown that leaf-scorch and chlorosis of certain fruit trees growing in the western counties of England are induced by potassium deficiency "which tends to promote physiological drought within the tree, especially when environmental conditions are conducive to drying-out, and the deficiency must generally be considered in relation to nitrogen supply" (3). Mann has further shown that the potassium content of leaves exerts a controlling influence on the rate of transpiration under conditions of high temperature and bright sunshine (4). In order to control leaf-scorch of fruit trees, Wallace has recommended that potassic manures be applied to the soil, or that the land be "grassed down" so as to diminish the uptake of soil nitrogen by the tree roots. Either or both of these treatments results in a lowering of the nitrogen/potassium ratio in the leaves, and favours the suppression of leaf-scorch. The soils of leaf-scorch areas in England have been grouped by Wallace (1) into:—

(a) Light sandy soils exhibiting low water-retaining capacity, and containing small potash supply.

(b) Compact silty soils underlain by impervious raw subsoils occasionally subject to water-logging.

(c) Heavy clay soils exhibiting unsatisfactory drainage conditions. In all these cases, a definite relationship appears to exist between environmental moisture conditions and mineral nutrition, especially with regard to the balance between the uptake of potassium and nitrogen, which seems to exercise a controlling influence on certain physiological processes occurring within the leaves.

In view of these findings, and of the results of related investigations at other stations, it was decided early in 1932 to inaugurate chemical studies on the composition of the leaves and other parts of cacao trees growing in different environments in Trinidad, and to study its possible bearing on the question of susceptibility of cacao to attack by Thrips. For the purposes of this chemical investigation, the foliage of cacao trees growing in the two contrasted "good" and "bad" plots, described in Part I of this report, was sampled and analysed in the laboratory. The bad plot has suffered marked Thrips attack during the two years of detailed observation, but the good plot has escaped attack, although neighbouring fields have shown severe Thrips damage within this period.

(2) Method of Sampling.

The cacao tree puts out several leaf-flushes during the year, so that it is difficult to obtain strictly comparable material from widely separated plots. The following procedure was therefore followed. Six trees of average appearance were selected in each plot, and samples of foliage were collected from them once in a fortnight. The most recent growth flushes only were sampled; when a fresh growth flush appeared, two sets of leaf samples were taken, one from the new flush, and one from the previous flush. When the leaves of the new flush had hardened, sampling of the old flush was not continued.

(3) Laboratory Results.

The following chemical determinations were made on the leaf material; (i) total dry matter, (ii) ash content, (iii) nitrogen content, (iv) phosphate content, and (v) potash content. The data obtained are presented in Tables IV to VII. In Table IV, the analytical results for the two contrasted plots are grouped into four leaf-categories, namely, (a) young-flush leaves, (b) young green leaves, (c) mature leaves, and (d) older mature leaves, sampled during subsequent growth flushes. In Table V, are presented data obtained by chemical analyses of foliage collected from an area severely attacked by Thrips. Tables VI and VII present comparable data statistically treated by the analysis of variance method which reveals significant differences in chemical composition between (1) leaves collected from the good and bad plots, and (2) young leaves and mature leaves.

(4) Discussion of Results.

The results obtained may best be summarised for the different leaf components determined, namely:—

(i) *Nitrogen*.—The nitrogen content of young leaves is definitely *lower* than that of mature cacao leaves.

(ii) *Phosphate*.—The phosphate content of young leaves is definitely *greater* than that of mature leaves.

(iii) *Potash*.—The potash content of cacao leaves fluctuates erratically as the leaves mature.

(iv) *Dry Matter and Ash*.—When nitrogen, phosphate and potash contents are expressed as percentages of total dry matter or of ash, highest values are shown by the young flush leaves.

(v) *Nitrogen/Potash Ratio*.—The ratio of nitrogen to potash is definitely higher in mature leaves than in young cacao leaves. Comparing

Table IV.

Average Chemical Composition of Leaves of two contrasted Cacao plots.

	YOUNG FLUSH.		YOUNG GREEN.		MATURE.		OLD MATURE.	
	Good Plot.	Bad Plot.	Good Plot.	Bad Plot.	Good Plot.	Bad Plot.	Good Plot.	Bad Plot.
Number of Determinations ..	5	6	5	4	10	8	6	8
FRESH MATERIAL.		(Parts per 10000)						
Nitrogen (N) ..	57	62	75	78	90	93	99	94
Phosphate (P_2O_5) ..	17	16	17	14	13	12	13	14
Potash (K_2O) ..	60	56	88	75	71	67	61	60
DRY MATTER.								
Nitrogen (N) ..	293	325	235	235	231	243	237	233
Phosphate (P_2O_5) ..	90	86	50	42	33	30	32	34
Potash (K_2O) ..	327	286	264	226	184	172	146	150
ASH CONTENT								
Nitrogen (N) ..	3380	4010	2390	2850	1900	1990	1780	1740
Phosphate (P_2O_5) ..	972	1060	510	510	270	250	250	250
Potash (K_2O) ..	3520	3590	2660	2790	1510	1420	1100	1100
ASH CONTENT OF DRY MATTER (Per cent.) ..	9.3	8.1	9.9	8.3	12.3	12.3	13.5	13.7
DRY MATTER IN FRESH MATERIAL (Per cent.) ..	18.5	19.3	33.4	33.2	38.8	38.4	41.9	40.5
RATIOS								
N/ K_2O ..	0.96	1.12	0.89	1.04	1.26	1.42	1.63	1.55
N/ P_2O_5 ..	3.50	3.87	4.66	5.55	7.04	7.96	7.12	6.95
K_2O/P_2O_5 ..	3.63	3.37	5.21	5.47	5.59	5.68	4.40	4.40

Table V.

Average Chemical Composition of leaves of healthy Cacao Trees and Trees attacked by Thrips.

		FLUSH LEAVES.		MATURE LEAVES.	
		Good Plot.	Thrips-attacked.	Good Plot.	Thrips-attacked.
Fresh Materials	Nitrogen Phosphate Potash	57 17 60	63 20 50	90 13 71	89 15 45
Dry Matter	Nitrogen Phosphate Potash	293 90 327	339 109 269	231 33 184	211 36 107
Ash	Nitrogen Phosphate Potash	3380 972 3520	3700 1190 2920	1900 270 1511	1490 250 750
Dry Matter in Fresh Material (Per cent.)		18.5	18.50	38.8	42.2
Ash Content of Dry Matter (Per cent.)		9.29	9.17	12.3	14.19
RATIOS	N/ K_2O N/ P_2O_5 K_2O/P_2O_5	0.96 3.50 3.63	1.27 3.12 2.46	1.26 7.04 5.59	1.96 5.98 3.00

Table VI.

Variation in Composition of Cacao Leaf foliage from different Plots.

Leaves.	Determination.	GOOD PLOT.			BAD PLOT.			Test of Significance t.
		D.F.	Mean Parts per 100000	Variance	D.F.	Mean Parts per 100000	Variance	
YOUNG LEAVES	Nitrogen	9	663	10072	9	687	16869	0.61 Not Significant.
	Phosphate	9	167	189	9	154	844	1.33 Not Significant.
	Potash	9	743	29792	9	635	31745	1.44 Not Significant.
RATIOS	N/K ₂ O	9	0.93	0.0145	9	1.10	0.0100	3.60 Def. Significant.
	N/P ₂ O ₅	9	4.06	2.7860	9	4.56	1.5085	0.79 Not Significant.
	K ₂ O/P ₂ O ₅	9	4.42	0.7061	9	4.21	1.2522	0.50 Not Significant.
OLD LEAVES	Nitrogen	9	896	2647	7	935	4141	1.48 Not Significant.
	Phosphate	9	126	671	7	118	788	0.65 Not Significant.
	Potash	9	710	7648	7	670	12479	0.88 Not Significant.
RATIOS.	N/K ₂ O	9	1.26	0.0478	7	1.42	0.0723	1.44 Not Significant.
	N/P ₂ O ₅	9	7.04	1.7451	7	7.96	3.1324	1.29 Not Significant.
	K ₂ O/P ₂ O ₅	9	5.59	2.6053	7	5.68	4.1616	0.11 Not Significant.

Table VII.

Variation in Composition of Cacao Leaf Foliage with Age.

Plot.	Determination.	YOUNG LEAVES.			OLD LEAVES.			Test of Significance t.
		D. F.	Mean Parts per 10000	Variance	D.F.	Mean Parts per 100000	Variance	
GOOD PLOT	Nitrogen	9	663	10072	9	896	2647	6.85 Def. Significant.
	Phosphate	9	167	189	9	126	671	4.61 Def. Significant.
	Potash	9	743	29772	9	710	7648	0.56 Not Significant.
RATIOS	N/K ₂ O	9	0.90	0.0145	9	1.27	0.0478	4.60 Def. Significant.
	N/P ₂ O ₅	9	4.06	2.7860	9	7.04	1.7451	4.64 Def. Significant.
	K ₂ O/P ₂ O ₅	9	4.42	0.7061	9	5.59	2.6053	2.12 Not Significant.
BAD PLOT.	Nitrogen	9	687	16869	7	735	4141	5.42 Def. Significant.
	Phosphate	9	154	844	7	118	788	2.81 Fairly Sig.
	Potash	9	635	31745	7	670	12479	0.54 Not Significant.
RATIOS	N/K ₂ O	9	1.09	0.0100	7	1.41	0.0723	3.70 Def. Significant.
	N/P ₂ O ₅	9	4.56	1.5085	7	7.96	3.1324	5.23 Def. Significant.
	K ₂ O/P ₂ O ₅	9	4.21	1.2522	7	5.68	4.1616	2.10 Not Significant.

the two plots, the ratio of nitrogen to potash in the young leaves of the bad plot is *higher* than that in the young leaves of the good plot; there is no significant difference in the nitrogen/potash ratio of the mature leaves of the two contrasted plots.

Thrips Attack.—The value for the nitrogen/

potash ratio of comparable leaf material taken from trees severely attacked by Thrips is relatively *very high*. The nitrogen content of the Thrips-affected leaves is of average magnitude, but the potash content is very low, resembling in this respect leaves taken from the bad plot which is also occasionally subject to Thrips attack.

(5) Conclusions.

The chemical aspects of cacao nutrition in relation to the effect of environment, and to susceptibility of attack by Thrips as indicated by the preliminary results so far obtained, suggests that a useful index of "physiological condition" is furnished by the nitrogen/potash ratio of the young leaf. This finding falls into line with the results obtained by Wallace and co-workers at the University of Bristol Agricultural and Horticultural Research Station, England, which have been described above. Whilst our investigations so far have been merely of a preliminary nature, it is evident that the subject deserves further intensive study, particularly since the results seem to throw light on the important practical problem of Thrips attack of cacao.

Thrips outbreaks are usually associated in the field with heavy, badly-drained soils, or with sandy soils liable to drought during periods of low rainfall, or with soils that are inadequately sheltered. Our environmental studies have indicated that Thrips may appear when a definite diminution in available soil moisture occurs, even though atmospheric humidity retains a high value; a condition of "physiological drought" may obtain during such periods, and this condition may be enhanced by a high nitrogen/potash ratio of the leaf, which appears to favour an increase in the rate of foliar transpiration.

(6) Suggestions for Further Investigations.

It is intended to study experimentally certain of the striking indications so far obtained in the chemical investigations described above.

(1) Measurements of actual transpiration rates of leaves or leafy-twigs of cacao trees growing in contrasted environments should be performed in the field.

(2) Attempts to modify the nitrogen/potash ratio of young cacao leaves by suitable manuring should be made :—

(a) by the application of potassic manures,

(b) by mulching with bulky organic manures or cellulosic materials which depress available nitrogen supply,

(c) by spraying cacao tree foliage with solutions of potassium salts,

(d) by altering the environment by suitable drainage and the formation of adequate shelter.

(3) Where possible, field experiments should be designed in such a way that the results obtained are amenable to statistical treatment.

(4) Chemical analyses of leaf material collected from cacao trees growing on different soil-types of known reputation should be made in order further to test the significance of the nitrogen/potash ratio in its relation to growth and productivity of the cacao tree and its susceptibility to the attack of Thrips, as well as of other known pests and diseases.

(5) Sand culture studies of the mineral nutrition of the cacao tree should be made. By this means it will be possible to study the effect of deficiencies of various elements on the growth of young cacao trees, under carefully controlled conditions.

(7) Summary.

(1) Cacao leaves of different stages of growth, and from two widely different environments have been examined in the laboratory.

(2) Analytical results are presented which demonstrate differences in composition between (a) leaves of different ages, (b) leaves from different plots.

(3) Cacao trees subject to the attack of Thrips show a high nitrogen/potash ratio in the young leaves.

(4) These findings have been considered in relation to the evidence obtained from recent researches carried out on fruit trees of temperate regions.

(5) The results have indicated that any practice which tends to lower the nitrogen/potassium ratio of young cacao leaves may be beneficial in reducing the susceptibility of the cacao tree to Thrips attack.

(6) Treatments suitable for field experiment have been outlined.

(8) References.

- (1) Wallace, T. Leaf Scorch on Fruit Trees. *Journ. of Pomol. and Hort. Sci.*, VI, 4, p. 243; VII, 1 and 2, p. 1, 1928.
- (2) Wallace, T. Investigations on Chlorosis of Fruit Trees. III. A Chlorosis of Plums due to Potassium Deficiency. *Journ. of Pomol. and Hort. Sci.*, VII, 3, p. 184, 1928.
- (3) Wallace, T. Some Effects of Deficiencies of Essential Elements on Fruit Trees. *Annals of Applied Biology*, XVII, 3, p. 650, 1930.
- (4) Mann, C. E. T. The Physiology of the Nutrition of Fruit Trees. I. *Univ. of Bristol Agric. and Hort. Res. Sta., Ann. Rept.*, 1924.

Fig. I. Torrecilla Estate "Good Plot." Relationship of Environmental Moisture to Growth of the Cacao Tree

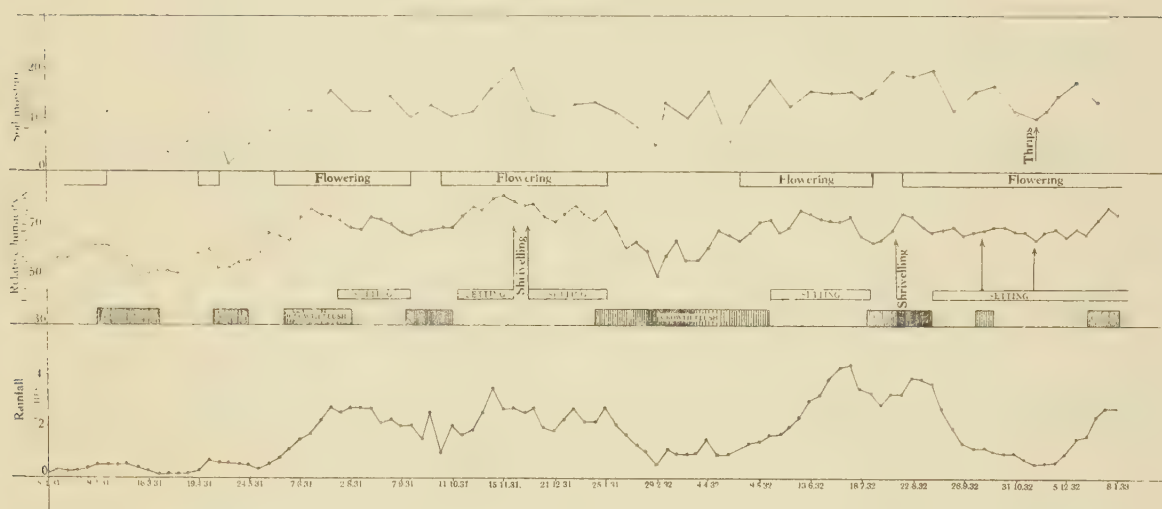


Fig. II. Las Hermanas Estate "Bad Plot." Relationship of Environmental Moisture to Growth of the Cacao Tree

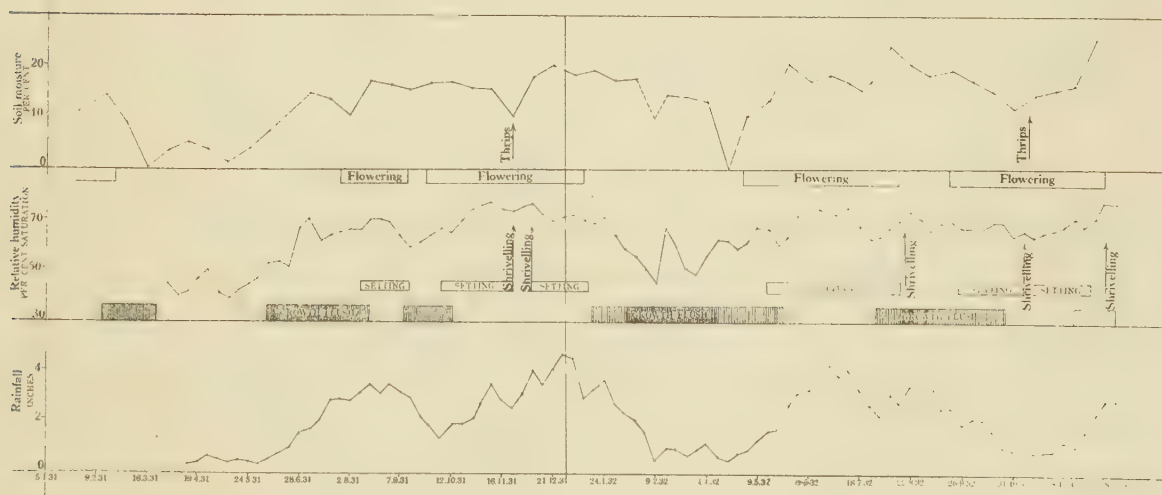


Fig. III
Soil moisture

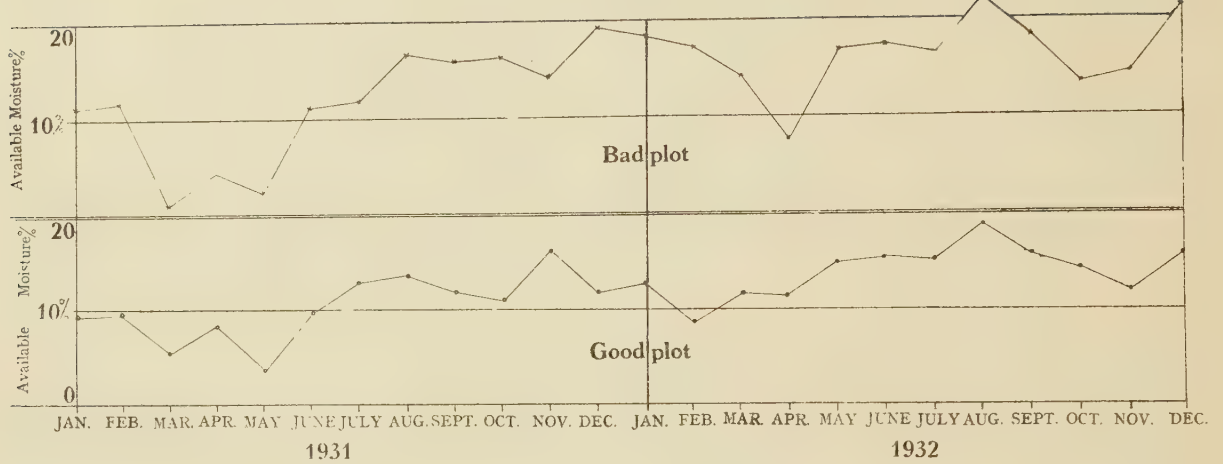


Fig. IV
Relative humidity

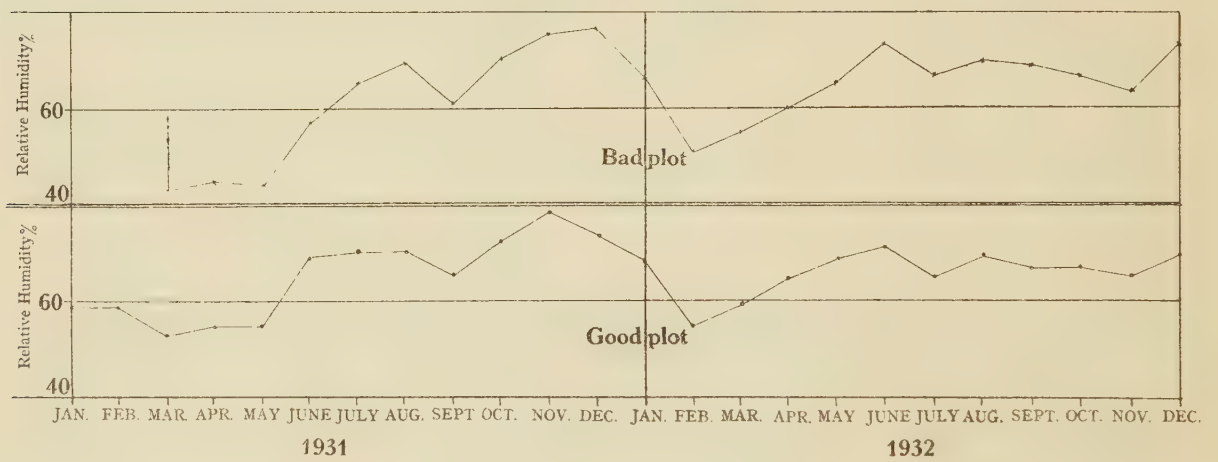


Fig. V
Evaporation

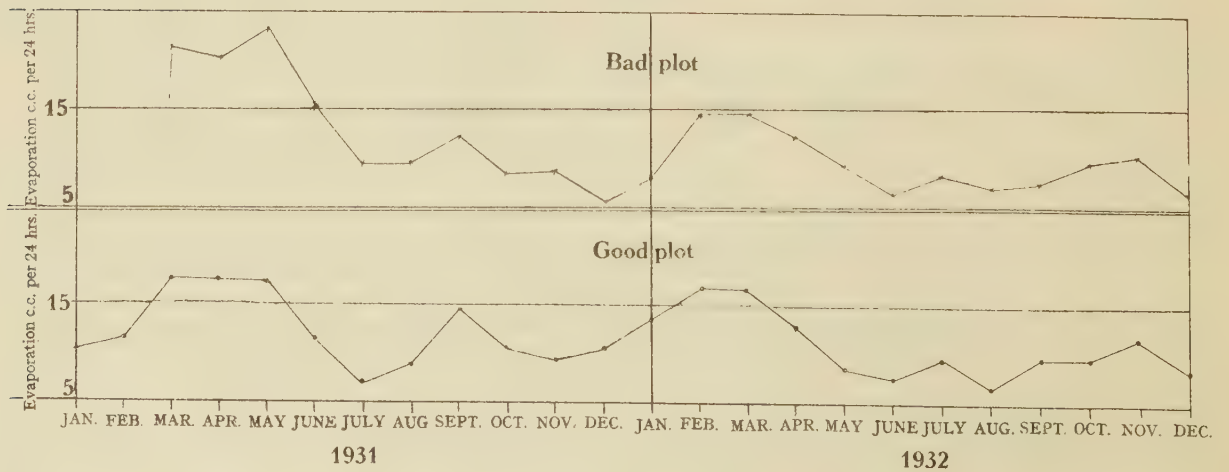


Fig. VI
Radiation

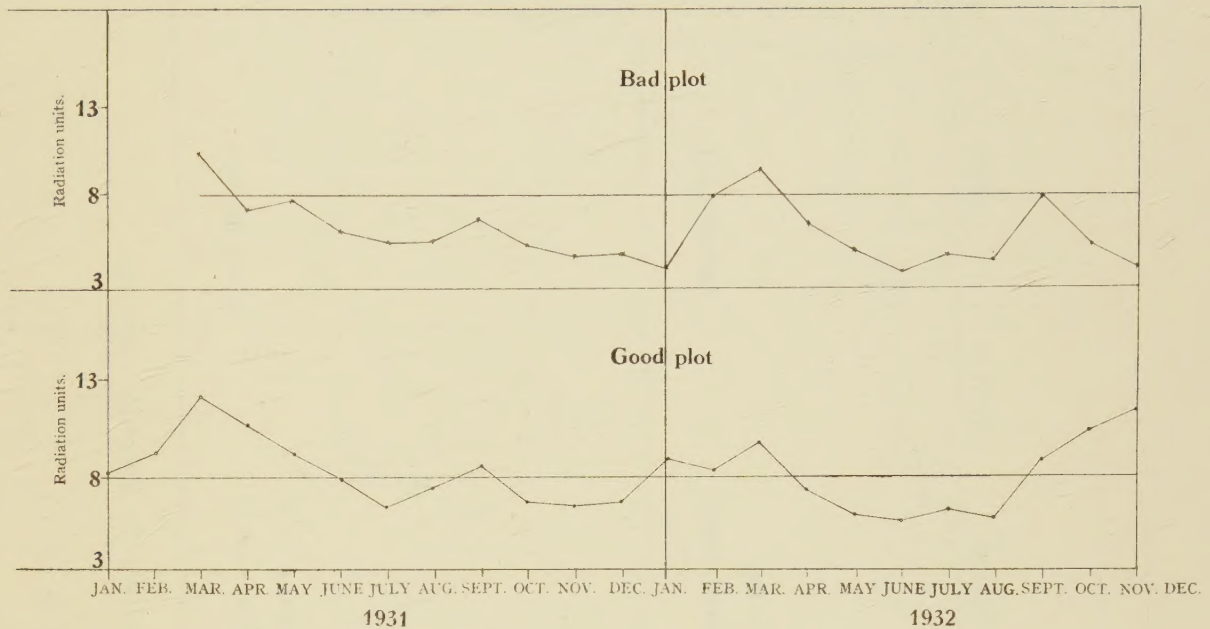


Fig. VII.
Temperature

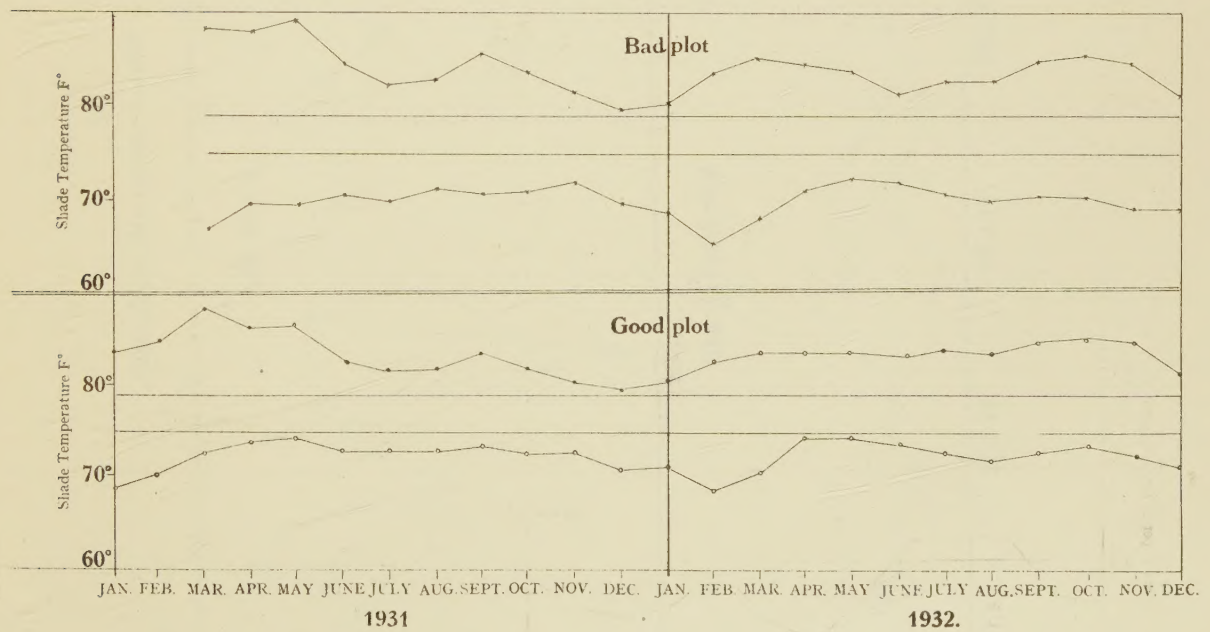


Fig. VIII Good plot soil, top six inch layer. Nitrate content and conductivity

